Atrial Septal Defect of Secundum type

A clinical study
before and after operation with special
reference to haemodynamic
function

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CHAPTER I

Introduction and aim of the investigation

The different anatomical types of atrial septal defect were described by Rokitansky in 1875, and in 1916 Lutembacher presented the combination of atrial septal defect and mitral stenosis. But it was not until 1941 that Bedford et al. described the physical signs and the electrocardiographic and roentgenological findings in atrial septal defect as a clinical entity. In 1947 the first cardiac catheterization in atrial septal defect was performed by Cournand et al.

Surgical treatment of atrial septal defect of the secundum type was introduced during the 1950's by Bailey et al. (1952), Björk & Crafoord (1953), and Søndergaard (1954), among others, with different closed methods. The results of open heart surgery under hypothermia in atrial septal defect were described by Lewis and Taufic (1953) and Blount et al. (1954), and with the aid of extracorporeal circulation by Lillehei et al. (1955), among others. Since this period a large number of reports concerning investigations of atrial septal defects have been published.

Since several literature reviews on this subject have already been made, the reader is referred to the works of Reindell et al. (1962), Schrire and Vogelpoel (1964), Derra, Grosse-Brockhoff and Loogen (1965) and Zaver and Nadas (1965).

The clinical picture and cardiological findings in atrial septal defect of the secundum type have been fully described and may be assumed to be well known. For the literature on this subject and the results of previous investigations, reference may thus be made to Wood (1956), Symposium on Atrial Septal Defect (1958), Kjellberg, Mannheimer, Rudhe and Jonsson (1959) and Davidsen (1960).

The natural history and prognosis in atrial septal defect of the secundum type has been greatly discussed. Roesler (1934), Burrett and White (1945) and Bedford et al. (1957) found a mean life expectancy of 36—39 years. Campbell et al. (1957) and also Wood (1962) found, however, that the prognosis in uncomplicated atrial septal defect of the secundum type was relatively favourable up to the age of 40—50 years, and according to Wood "the object is to prevent considerable morbidity between the ages of 50 and 60 and to prevent death between the ages of 60 and 70".

According to Adams (1965) a large left-to-right shunt in atrial septal defect of the secundum type can be tolerated even up to the ages of 70—80 years. On the other hand, attacks of cardiac failure during the first year of life have been described by Nakamura and Nadas (1964), among others, and according to Kavanagh-Gray (1963) death may occur at this age.

Since the long-term prognosis in atrial septal defect of the secundum type, although difficult to assess, is not entirely favourable, and since the operation mortality is low, Derra et al. (1965) conclude that in general, operation is indicated if the left-to-right shunt is 30 per cent or more of the pulmonary blood flow. A predominant right-to-left shunt due to raised pulmonary resistance should constitute a definite contraindication to operation, as also should therapy-resistant myocardial insufficiency.

The operation mortality in different series of cases is always difficult to evaluate, and varies amongst other things according to the selection of cases for surgery. In an analysis made by the Committee on Cardiovascular Surgery, American College of Chest Physicians (1963), a mortality of 3 per cent was reported in 397 patients operated on with different closed methods, while 542 patients had undergone operation under hypothermia, with 3 per cent mortality, and 1206 patients operated on under extracorporeal circulation showed a mortality of 4 per cent.

In a series of 206 "good risk" patients with uncomplicated secundum defects subjected to operation under hypothermia, Sellors (1961) reported a total mortality of 0.5 per cent, and approximately the same result was obtained by Derra et al. (1965) with only two deaths among 215 such patients. Derra states that the total operation mortality in atrial septal defect of the secundum type is now probably lower than 2 per cent in most thoracic surgical centres. In view of the gradual reduction of the operation mortality in open repair of atrial septal defects of the secundum type, it is sometimes considered that the diagnosis in itself constitutes an indication for operation (Zimmerman 1958, Mustard 1961, Gasul et al. 1961), but other authors (Taussig 1960, Gross 1962, Wood 1962) are of the opinion that with small defects, which are usually compatible with a normal life, operation is not usually indicated.

Partly owing to variations in the selection of patients and the operation technique, the operation results in different series of cases, often expressed as the mortality rate and the number of residual shunts, are difficult to compare. In one of the first investigations made after closed heart operations in atrial septal defect, Kirklin et al. (1956) found 6 residual shunts in 20 recatheterized patients, among 32 operated on by the Gross method. At the same time "a mild drop in pulmonary artery pressure even when it has been within the range of normal prior to operation" was shown.

Søndergaard (1962) found a functionally closed defect in all except one of 66 recatheterized patients in his own operation series, although the defect was completely closed in only 54 patients. Carlgren (1961) found small residual shunts in 9 of a smaller series of 24 patients operated on by the same method.

Residual left-to-right shunts have also been demonstrated after open repair of atrial septal defects. These have usually been of a lower frequency but varying figures of up to 20 per cent are reported. Bedford et al. (1957) investigated 40 patients after operation under hypothermia, including 12 with cardiac cathe-

terization. A residual shunt was shown in 5 patients. Winchell and Bashour (1958) compared the haemodynamic conditions at rest before and after operation under hypothermia in 20 patients with atrial septal defect of the secundum type, and found a residual left-to-right shunt in only 1 patient, who was found at operation to have an undiscovered anomalous pulmonary vein opening into the superior vena cava. In summary these authors state that "closure of the atrial septal defect brought about the changes that one would anticipate such as reduction of pulmonary blood flow and pulmonary artery pressure to normal if it was initially elevated".

Among 65 patients with atrial septal defects of the secundum type, catheterized after operation under hypothermia, Sellors (1961) found small residual shunts in 7 patients "operated on in the early days of open heart surgery".

A large series of followed up uncomplicated atrial septal defects of the secundum type is reported by Loogen and Toker (1961) who examined 100 patients 1—6 years after operation under hypothermia. Of these patients 43 were recatheterized 4—6 weeks after operation, and 7 (16 per cent) were then found to have a residual shunt. In the remaining cases changes of the physical, electrocardiographic and roentgenological findings indicated that the defect was closed.

In a series of 30 secundum defects examined by cardiac catheterization 1—4 years after operation under hypothermia, Reindell et al. (1962) gave a full report of the roentgenological findings before and after operation. A residual left-to-right shunt was noted in 2 patients of this series.

The subjective improvement, and alterations in the physical cardiac findings and electrocardiographic and roentgenological conditions after closure of atrial septal defects are, as a rule, described together with the catheterization results, and such reports have been made by Bedford et al. (1957), Loogen and Toker (1961) and Reindell et al. (1962), among others.

An analysis of postoperative changes has been made recently by Derra, Grosse-Brockhoff and Loogen (1965). The electrocardiographic findings before and after repair of atrial septal defect have been described especially by Davies et al. (1960) and Lee and Scherlis (1962); in these series, however, no catheterization data are given to show that the defect has been closed.

Up to the present no comprehensive study of a large series of patients following open repair of atrial septal defect appears to have been reported.

Aim of the investigation. The present investigation is based on 105 patients recatheterized 17.3 months, on the average, after open correction of an *atrial septal defect of the secundum type* (ASD sec), with or without partial anomalous venous return, and 2 patients with partially anomalous venous return but with no defect.

The aim of the investigation was to compare:

1. The clinical and cardiological findings before the operation and at the follow-up examination in a series of patients in whom heart catheterization

had proved complete closure of the defect.

2. The haemodynamic findings at rest before and after the operation.

3. The haemodynamic conditions in a number of these patients, during work, after the operation, with conditions in normal persons.

4. The haemodynamic findings at rest and during work in a number of patients, both before and after the operation, in greater detail, and also to compare these results with conditions in normal persons.

CHAPTER II

Case material

Collection of the material was begun in 1958, when open repair under hypothermia was introduced as a routine operation method for atrial septal defect of the secundum type at the Department of Thoracic Surgery, University Hospital, Uppsala. Up until June 1964, 115 patients with this diagnosis had been operated on by V. O. Björk personally, head of the department at that time. Of these, 107 patients were followed up and form the basis of this study. Five patients were not available for follow-up examination, and a further three patients had died.

The majority of these patients had been remitted to the Cardiac Division of the Medical or Paediatric Medical Clinic, University Hospital, Uppsala, from different hospitals, with a preliminary diagnosis such as "congenital heart disease" or "atrial septal defect", for investigation and decision as regards surgery. The diagnosis was then established by means of a complete cardiological investigation. The indication for operation was a left-to-right shunt on the atrial level of at least 30 % of the pulmonary blood flow. In no case was there a predominant right-to-left shunt on the atrial level, or any other contraindication for operation.

Mortality. There was no primary operation mortality. The total mortality hitherto has comprised 3 patients (2.6 %). One 33-year old woman died of a cerebral embolus 9 days after the operation. In one 42-year old woman a postoperative regularized fibrillation necessitated the continuation of anticoagulant therapy after her discharge from hospital. This patient died at her local hospital 2 months after the operation, of a cerebro-vascular complication which was probably drug induced. The third patient, a 35-year old woman, died 3 years after the operation in cardiac failure. At the operation a left-to-right 80 % shunt was found, and moderate pulmonary hypertension with a systolic pulmonary arterial pressure of 50 mm Hg. Roentgenologically this patient exhibited marked cardiac enlargement with a relative volume of 1420 ml/m^2 body surface area, expressing pronounced myocardial insufficiency. Postoperatively there was no residual shunt, and there was some subjective functional improvement, but there was a manifest, therapy-resistant cardiac insufficiency with pronounced cardiac enlargement and a roentgenological volume of 1000 ml/m^2 body surface area.

Age and sex. The patients were divided into the following three age groups according to age at the time of operation.

Age group A comprised a paediatric group of 50 patients who were operated on before the age of 15 years.

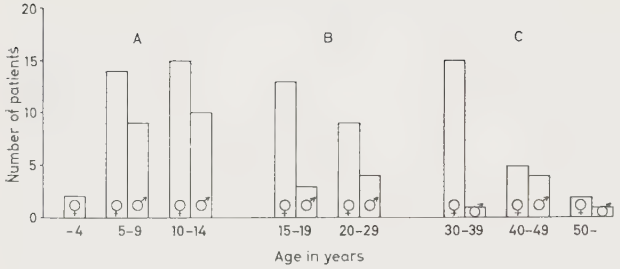


Fig. 1. Distribution of patients at time of operation, by age and sex.

Age group B comprised a group of 29 young adults who were operated on at the ages of 15—29 years.

Age group C comprised a group of 28 older adults, who at the time of operation were 30 years old or older.

The youngest patient was 3 years old at the time of operation, and the oldest 62 years.

The material consisted of 75 women and 32 men, the ratio of women to men being thus 2.3: 1. The sex distribution varied somewhat in the different age groups. In age group A there were 31 girls and 19 boys (ratio 1.6: 1). Age group B comprised 22 women and 7 men (ratio 3.1: 1), and age group C 22 women and 6 men (ratio 3.7: 1). The age and sex distributions at the time of operation can be seen in Fig. 1.

Operation methods. Open repair of the atrial septal defect under hypothermia was performed in 94 of the 107 patients investigated. In 13 cases the operation was carried out with the aid of extracorporeal circulation: In one 7-year old girl extracorporeal circulation was used because of uncertainty in the diagnosis; ASD of primum type could not be excluded with certainty. Two young adult patients in age group B, who had previously undergone surgery by the Søndergaard method, were re-operated on with the aid of extracorporeal circulation. Among the older adults of age group C, extracorporeal circulation was used in 3 patients in whom ASD of primum type could not be excluded with certainty, and this method was also preferred in a further 7 patients with a large left-to-right shunt. The surgical method for correction of ASD sec has been described in detail previously by V. O. Björk et al. (1960) and for correction of anomalous venous return by V. O. Björk et al. (1962).

Postoperative complications. In 5 adult patients cerebral emboli occurred during the first few days postoperatively. In 1 of these patients the outcome was fatal. The remaining 4 patients showed rapid clinical improvement, and on discharge from hospital there were no clinico-neurological abnormalities.

Fourteen patients, 12 of whom were older persons with a large left-to-right shunt and cardiac enlargement, required postoperative respirator treatment for an average of 7.5 (1—26) days.

In one patient a cardiac rhythm disturbance (A-V block III) occurred during the operation, and this necessitated continuous pacemaker treatment. In 10 adult patients local infection occurred in the thoracotomy wound, and in some cases this prolonged considerably the pe-

riod of postoperative care. One child developed a bacterial hepatic venous thrombosis, and one adult patient bacterial pericarditis, but both recovered.

Period of postoperative care. The duration of *hospitalization* after the operation was, on the average, 21 (12—45) days for children, 36 (14—120) days for the younger adults and 40 (20—100) days for the older adults.

The *convalescence period* was also considerably shorter for the children, being 3.5 (2—12) weeks compared with 11.5 (12—36) weeks for the younger and 20.5 (12—60) weeks for the older adults.

Observation time. The observation time between operation and follow-up examination was, on the average, 17.3 months, with some variation between and within the different age groups. On the average the children were investigated 8 (5—33) months and the adults 25 (15—70) months after the operation. This difference is explained by the fact that the children were called for follow-up as routine within 1 year after the operation, whereas the adult patients were called in especially for this investigation, the patients who were operated on earliest being followed up first.

In the following, the term postoperative refers to the time of the follow-up examination.

Types of defect. At operation 55 patients were found to have a central secundum defect. Twenty-two patients had a large, low secundum defect, and in 12 of them this was of the inferior vena cava defect type with no posterio-caudal margin. Twenty-seven patients had a sinus venosus defect, which in 17 cases was combined with partial anomalous venous return. A further 3 patients had anomalous venous return, in one case combined with a large central defect and in two cases with no apparent defect. The frequency of partial anomalous venous return in the entire material was 18.7 %. In 15 patients with a sinus venosus defect, and in two cases with no visible defect there was right-sided anomalous venous return to the superior vena cava, in two cases to the right atrium and in one patient to both the right atrium and the inferior vena cava.

Other cardiac malformations. In 5 patients other, complicating cardiac malformations were found. Three women had mild valvular pulmonary stenosis. In 2 of these cases double repair was carried out at the operation, whereby the atrial septal defect was first closed, and valvulotomy was then performed. From a haemodynamic aspect, however, the atrial septal defect predominated over the pulmonary stenosis, and these patients were therefore included.

Two patients with mitral insufficiency, a woman and a man both of age group C, had both had rheumatic cardiac disease. The man underwent operation with the aid of extracorporeal circulation, at which a mitral annuloplasty was performed at the same time. In the woman there appeared to be no indication for treating the mitral insufficiency when the atrial septal defect was repaired. Myocarditis had occurred in 2 children. One of them, a 7-year old boy had had viral myocarditis (influenza type A) and also, two years later, rheumatic myocarditis. The other child, a girl, had had probable viral myocarditis

in her infancy. In neither of these cases were valvular changes observed on examination or operation. There were no patients with both atrial septal defect and mitral stenosis (Lutembacher's syndrome) in this series.

There were no patients with a history of endocarditis lenta in this series.

Discussion

The present material comprises a series of operation cases of atrial septal defects of the secundum type, where by chance there were no severe haemodynamic complications. It has been found that in cases where partial anomalous venous return is present in addition, this produces no change either in the clinical picture or the haemodynamic findings (Kjellberg et al. 1959), and patients with such a condition were therefore included in the ASD series.

It must be accepted that in a clinical investigation of this type there will be some degree of change in the material due to time-dependent factors such as body growth. Usually it is assumed that the haemodynamic conditions will not have returned to normal after repair of an atrial septal defect of the secundum type until about a year after the operation (Reindell et al. 1962). In most of the adult patients in the present series the postoperative observation period was considerably longer, but in other cases the period was shorter. Nevertheless certain results obtained at the follow-up examination were used for comparisons, since the observation periods in the different age groups were considered sufficiently long.

The total mortality during the period covered by the investigation was 2.6 %. When, however, the mortality was calculated on the basis of operative and postoperative death, i. e. within 10 days after the operation (Nordlund 1966), it was only 0.9 %. The two deaths occurring 2 months and 3 years after the operation, respectively, were late deaths (after 10 days) and should not be included in comparisons with other operation mortality figures. This operation mortality of 0.9 % is thus of the same order of size as has been reported by Sellors (1961) and Derra et al. (1965), among others.

In evaluations of the operation risk in uncomplicated atrial septal defect of the secundum type, the most suitable age for operation has been discussed. In this series the age distribution at the time of operation was in agreement with that usually seen in ASD sec (Bedford 1961, Zellos 1964). Even if the operation risk increases with advancing age, a high age is not considered in itself to be a contraindication to operation (Ellis et al. 1960); however, the optimal age for closure of an atrial septal defect of the secundum type is considered to be between 5 and 15 years (Mark 1963). In the present series this corresponds to the patients in age group A, and for these patients both the period of postoperative care and the convalescence period were considerably shorter than for the young and older adults.

The sex distribution in the whole material agreed with that usually reported in secundum defects (Derra et al. 1965, Himbert et al. 1965). The reason for the predominance of women over men in the

older age groups is probably not an excess mortality in the men, but could perhaps be that with symptoms of the type suffered by these patients, medical advice is more often sought by women than men (Campbell and Polani, 1962).

Distributions of defect types in operation series have been reported only seldom, but the distribution in the present material is in approximate agreement with the similarly classified series of Sellors (1961) and Arntzenius et al. (1963). The central or fossa ovalis defect constituted 60—80 % of all defects. The frequency of partial anomalous venous return was in the present series 18.7 %, which is in agreement with the figures of 10—20 % reported by Derra et al. (1965).

The frequency of malformations of the mitral valve in patients with atrial septal defect varies in different series (Bedford et al. 1957, Derra et al. 1965), being partly dependent on the incidence of rheumatic fever among the population, and the age composition of the material. In Sweden the incidence of rheumatic fever has long been low (Hall 1961), which may explain the low frequency of rheumatic mitral valvular disease in this series.

CHAPTER III

Methods

The mode of investigation was the same preoperatively as at the follow-up examination. On both occasions the patient was hospitalized, the period of hospitalization being about 7 days for the preoperative examination, and 3—4 days for the follow-up.

In all cases these investigations comprised a general clinical examination with full examination of the physical cardiac state, electrocardiogram and phonocardiogram, chest roentgenogram and cardiac catheterization. On catheterization the pressure and flow were determined at rest and during exercise both pre- and postoperatively in 18 patients, using the same work load on each occasion, and postoperatively alone in 51 patients.

General clinical examination. Physical examination was performed personally by the author in all of the follow-up, and also in most of the preoperative investigations, particularly in the children. The case history data concerning the symptoms and functional capacity were evaluated and used as a basis for division into function classes. For adults, function classes as suggested by the New York Heart Association (1964) were used, and for children a modification of Davidsen's classification (1960). The general condition was assessed with especial regard to cardiac failure and complicating diseases, and to any further congenital malformations.

The physical cardiac state was evaluated with respect to palpatory precordial activity and auscultatory findings. The palpatory findings were assessed, and signs of increased right ventricular activity were noted. The intensity of the first sound, the degree and variability of splitting of the second sound and the amplitude of the pulmonary component were assessed. The distribution and site of the murmur were determined and the systolic murmurs graded according to Levine & Harvey (1959) at the position of their maxima. Routine blood and urinary analyses were carried out.

Electrocardiogram (ECG). In the great majority of cases the ECG was recorded with a four-channel direct-writing apparatus (Mingograf 42, Elema-Schönander Ltd., Stockholm), and in only a few patients before 1959 was the recording made on a three-channel apparatus (Triplex, Elema). Leads I, II, III, aVR, aVL and aVF were used, and also, in adults precordial leads V_1—V_7, and in children precordial leads V_1—V_6.

On evaluation of the QRS complex and the P and T waves, the amplitudes were measured from the isoelectrical line, i. e. a line drawn between two TP segments. The mean value of at least

three heart cycles was used. With high QRS amplitudes the amplification was reduced so that one mV corresponded to 5 mm, compared with the usual 10 mm. The paper speed was 50 mm/sec. The mean QRS axis in the frontal plane was calculated in the usual way with values for axis deviation according to Goldman (1960).

For checking the rhythm postoperatively, usually only standard and extremity leads could be used for the first 6—8 days because of the extent of the operation wound. At the exercise tests ECG was recorded in the recumbent position, after 8 minutes of passive standing, during exercise, in the sitting position and both immediately and 4 and 10 minutes after exercise in the recumbent position. During exercise a CH lead with the indifferent electrode on the forehead was used (Sjöstrand, 1951, Holmgren and Strandell, 1961).

Phonocardiogram (PCG). The calibrated phonocardiogram was recorded by means of the same four-channel ECG direct-writing apparatus with a phono-preamplifier. Usually filters with nominal frequencies of 25 c/s and 100 c/s, and an auditory amplification (Kjellberg et al. 1959) were used. The paper speed was 100 mm/sec. The recordings were made after normal expiration, over the second right, the second and third left and the fourth left intercostal spaces, and over the apex. Special "respiratory phonocardiograms" for the evaluation of the second sound during ordinary inspiration and expiration were recorded. The time interval between the sound components was determined from the mean of at least 5 measurements, this interval being measured between the initial maximal amplitudes of the different components.

Basal metabolic rate. The basal oxygen uptake was measured by means of double determinations of ten minutes' duration each, using a "Spirograf Krogh" or "Spirograf IV" (Elema-Schönander Ltd., Stockholm).

Physical work capacity. A work test with step-wise increases of the load (Sjöstrand, 1947; Wahlund, 1948) was carried out in the usual way on an electrically braked bicycle (Holmgren and Mattsson, 1954). The heart rate was determined after 2, 4 and 6 minutes, and the respiratory rate was counted after about 3 minutes at each load. The ECG was monitored continuously on the oscilloscope, and was recorded after 5 minutes at each load. For children under 12 years of age the first load was usually 100 kpm/min, for older children and women 200 kpm/min and for men 300 kpm/min. The test was discontinued when the pulse rate reached approximately 170 beats/min, or earlier in the event of objective or subjective signs of an abnormal reaction. The work capacity corresponding to a heart rate of 170 beats/min (PWC_{170}) was obtained by means of extrapolation or interpolation and was expressed as kpm/min per kg body weight. Work capacities of 600 kpm/min for women and 900 kpm/min for men were usually regarded as normal. The children were evaluated according to Sterky (1963).

Heart volume. The heart volume was determined with the patient in the sitting position according to the method of Jonsell (1939), and the relative heart

TABLE 1. Heart size, ml/m² BSA, according to X-ray groups in children, women and men.

Heart size	Children	Women	Men	
Normal	⩽350	⩽450	⩽500	ml/m² BSA
Slight enlargement	>350—500	>450—600	>500—650	»
Moderate enlargement	>500—650	>600—750	>650—800	»
Pronounced enlargement	>650	>750	>800	»

volume is given in ml/m² body surface area. The group classification can be seen in Table 1.

Lung function tests. The lung volumes and ventilation capacity were determined with a "Spirokombi" (Kifa Ltd., Stockholm). The vital capacity (VC), forced expiratory volume in one second ($FEV_{1.0}$) and maximum voluntary ventilation with a fixed respiratory frequency of 40 (MVV_{40}) and with a free respiratory frequency (MVV_f) were measured. By FEV % is meant $FEV_{1.0}$ expressed as a percentage of VC or FVC (forced vital capacity) depending on which is the greater.

Cardiac catheterization. Before the first catheterization the patient was well informed about the investigation; there were no difficulties in obtaining the patient's cooperation for follow-up catheterization after the operation. In the morning, approximately 1 hour before the catheterization, the children were given a small dose of morphine (5—7 mg) subcutaneously, and the adults were given a small oral dose of Pentymal (0.1—0.2 g). The catheterization was performed with the patient in the recumbent position. A polyethylene catheter was introduced into the brachial artery by the usual percutaneous technique. The venous catheter was usually introduced via an exposed superficial cubital vein, but in some cases, especially children, the saphenous vein was preferred. In most cases the defect was demonstrated preoperatively by means of the catheter. In many cases, especially with catheterization via the superior vena cava, a good idea of the position of the defect in the septum could be obtained by manipulation of the catheter, as has been described by Gøtzsche (1962). Shunts were usually determined preoperatively from the oxygen saturation values with relatively rapid withdrawal from the pulmonary artery to the superior vena cava. An increase in oxygen saturation of 10 per cent in one set of samples between the superior vena cava and the pulmonary artery is regarded as evidence of a left-to-right shunt (Nadas, 1963). It is routine at our Centre to express the size of the left-to-right shunt as per cent of the pulmonary blood flow, Q % LR, (Hamilton and Dow, 1962) as follows:

$$Q\,\%\ LR = \frac{C_{PA_{O_2}} - C\bar{v}_{O_2}}{C_{PV_{O_2}} - C\bar{v}_{O_2}}$$

$C_{PV_{O_2}}$ and $C_{PA_{O_2}}$ are the oxygen contents of pulmonary vein and pulmonary artery samples, respectively, and $C\bar{v}_{O_2}$ is the oxygen content of mixed venous

blood. The left-to-right shunt expressed in this way has been compared with the ratio of the pulmonary blood flow, $\dot{Q}_p$, to the systemic flow, $\dot{Q}_s$ (Table 2). On the basis of these considerations the following three "shunt groups" were used:

Shunt group 1: Left-to-right shunt of less than 50 % of the pulmonary blood flow, corresponding to a $\dot{Q}_p : \dot{Q}_s$ ratio of less than 2: 1.

Shunt group 2: Shunt of 50—65 %, corresponding to a $\dot{Q}_p : \dot{Q}_s$ ratio equal to or more than 2: 1 but less than 3: 1.

Shunt group 3: Shunt of 66 % or more, corresponding to a $\dot{Q}_p : \dot{Q}_s$ ratio equal to or more than 3: 1.

The pressure and ECG recordings were made on a direct-writing four-channel ECG apparatus (Mingograf 42). The mean pressure was obtained by electrical integration. Pressures were usually recorded continuously on withdrawal curves from the pulmonary capillary venous position to the superior vena cava for the evaluation of any valvular stenoses. In many cases the pressures in the left atrium and ventricle could be recorded preoperatively via the defect.

No complications occurred on right heart catheterization either preoperatively or at the follow-up examination, nor at the preoperative left heart catheterization performed in 47 patients.

For flow determination the catheter was placed in the pulmonary artery. The cardiac output was measured by the direct Fick method. Pressure recordings were made and blood samples taken during the 5th to 8th minutes at rest and 4th to 6th minutes during exercise. Expired air was collected for 10 minutes with the patient at rest, and for 3 minutes during exercise, between the 3rd and 6th minute of each load, with the Douglas bag technique. Gas analyses were performed according to the Haldane technique (Enghoff 1946). Normal values for oxygen consumption were obtained from current tables (Harris and Benedict, 1919; Nadas, 1963).

Table 2. Size of left-to-right shunt expressed as per cent of pulmonary blood flow, compared with $\dot{Q}p:\dot{Q}s$ ratio.

Left-to-right shunt % of pulmonary blood flow	Pulmonary blood flow ($\dot{Q}p$) in relation to systemic flow ($\dot{Q}s$)
33	1.5:1
50	2 :1
66	3 :1
75	4 :1
80	5 :1
83	6 :1
87	7 :1
89	8 :1

Oxygen saturation. In most cases, where repeated oxygen saturation determinations were made at short intervals, a Kipp haemoreflectometer (Kipp and Sons Company, Delft, the Netherlands) was usually used, according to the method originally described by Zijlstra (1953). This method was employed in comparisons of pre- and postoperative saturation values. For flow determinations the oxygen saturation was measured by spectrophotometry of haemolysed whole blood, as described by Holmgren and Pernow (1959). The haemoglobin concentration was determined spectrophotometrically as cyanmethemoglobin.

Statistics. The arithmetical mean, standard deviation (SD) and standard error of the mean (SE) were calculated by the conventional methods. Student's *t*-test was used to determine the significance of the differences in the various variables between preoperative and postoperative values. The studies of relations between the different variables were performed on the basis of the correlation coefficients where the significance was also determined by the *t*-test (Snedecor 1956).

The significance levels applied were as follows:

$0.05 \geqslant P > 0.01 = (*)$
$0.01 \geqslant P > 0.001 = (**)$
$0.001 \geqslant P = (***)$

These values correspond to the usual terms "probably significant", "significant" and "highly significant", respectively.

CHAPTER IV

Clinical findings before and after operation

Growth and physical development

The height and weight in relation to age were determined in 66 patients below 20 years of age (45 girls and 21 boys). There was some tendency to underweight, especially in the younger patients, but in only a few were the values found to lie outside the normal (± 2 SD) range limits for Swedish children (Karlberg & Iggbom, 1959), as can be seen in Fig. 2. In some patients the weight was lower than the normal at the follow-up examination also, in spite of a normal weight increase.

Height in relation to age at operation. In 61 of the 66 patients the height in relation to age was within the normal range for healthy Swedish children. In 2 boys the height was below the lower range limit, and in 2 other boys above the upper limit, but in all four boys the weight was normal. In one patient there were hereditary factors to explain her short stature (a Lapp girl).

Weight in relation to height at operation. Only in 5 patients, 4 girls and 1 boy, was the weight found to be below the normal limit, but in all of these patients except one the height-age relationship was normal. The exception was a 14-year old boy who was unusually tall and gracile, with a height of 20 cm above and a weight of 5 kg below the normal limits of variation. One girl had a pronounced weight excess.

Height in relation to age at follow-up examination. At the follow-up examination it was found that the height increase was normal, and agreed with the growth diagram. In 2 out of 3 patients whose preoperative height lay somewhat outside the normal limits of variation, the height increase was normal. The third, the gracile boy mentioned above, had increased in height by a further 13 cm to 203 cm in 18 months.

Weight in relation to height at follow-up examination. In 9 girls at the age of puberty the weight increase was rather more pronounced than the normal. In two of these the weight before the operation lay below the normal limit. In two patients the weight still lay below the normal limit in spite of a normal weight increase. One 18-year old girl who was considerably overweight preoperatively, increased a further 20 kg. In the remaining patients the weight increase was normal. Preoperatively the weight in relation to height lay near the lower normal limits in patients up to 15 years of age, but postoperatively there was a weight increase which meant that the deviation from the mean value diminished significantly (*).

In 41 patients of ages 20—67 years, the weight—height relationships showed no special tendencies either pre- or postoperatively.

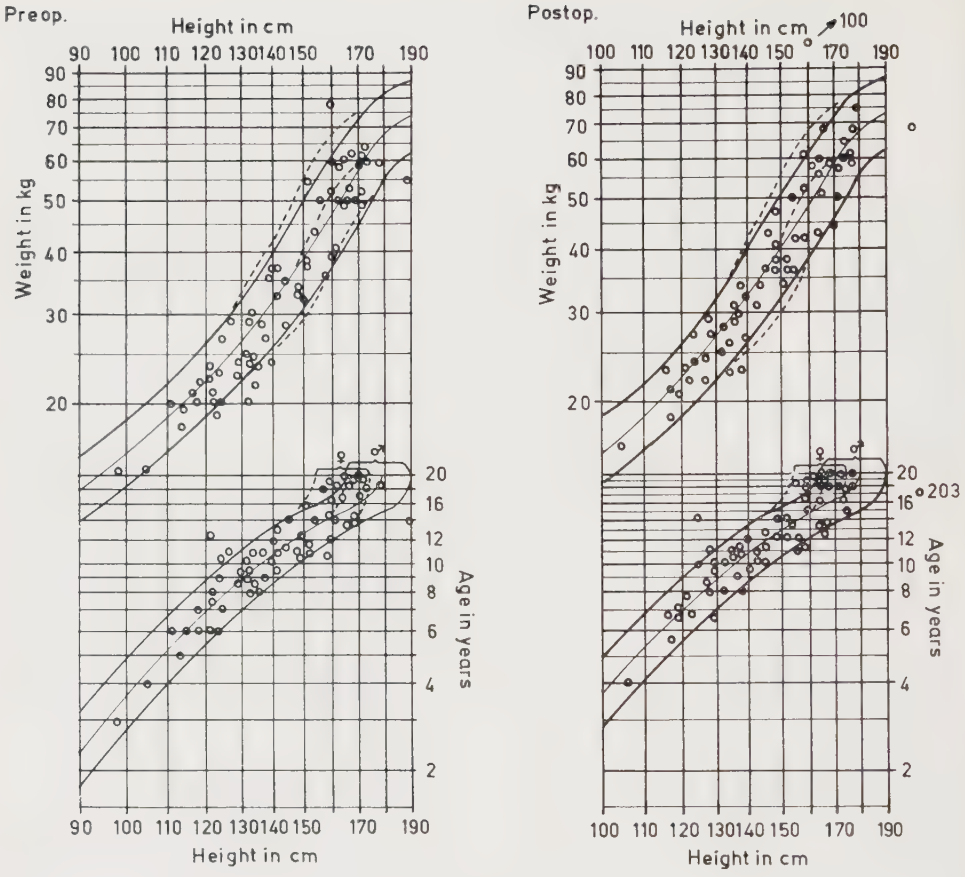


Fig. 2. Physical development in 66 patients before (A) and after (B) operation. — The growth diagram gives the height in relation to age, and weight in relation to height, mean value ± SD, in healthy Swedish children, according to Karlberg and Iggbom (1959).

Symptoms

The symptom pictures in the different age groups among a total of 44 patients with a history of functional reduction are shown in Table 3. The predominant symptoms at all ages were increased exhaustibility and breathlessness, these occurring as the only symptoms in 36 out of 38 patients in function class II; two patients in age group B stated that they had no increase in exhaustibility, despite their breathlessness. 9 patients also had palpitations, which in two of them were associated with precordial pain.

Only age group C included patients with pronounced subjective symptoms, 6 of them being assigned to function class III. These six patients had increased exhaustibility, breathlessness and palpitations on mild effort, and 5 of them also suffered from precordial pain in association with the palpitations. One woman

TABLE 3. Distribution of some commonly recorded symptoms before operation according to age groups and function classes.

Age group	No. of patients	Function class	No. of patients	Symptoms			
				Increased exhaustibility	Breathlessness	Palpitations	Precordial pain
A	50	II	9	9	9	—	—
B	29	II	13	11	13	4	1
C	28	II	16	16	16	5	1
		III	6	6	6	6	5
Total	107		44	42	44	15	7

TABLE 4. Circumstances associated with the discovery of the heart disease distributed according to age groups.

Occasion		Age group			Total
		A	B	C	
Public health examination	Child Welfare Clinic	12	4	—	16
	At school	19	11	8	38
	Mass radiography	3	5	2	10
	During pregnancy	—	—	9	9
Other health examination		—	3	2	5
					78
Examination for non-cardiac disease	Bronchitis	4	—	1	5
	Other infections	4	—	1	5
	Other diseases	7	4	3	14
					24
Examination for cardiac symptoms	Dyspnoea	—	1	1	2
	Tachycardia	—	1	1	2
	Precordial pain	—	—	1	1
					5

of age group C had precordial pains of a suspected angina pectoris type. One patient in function class III, with pulmonary hypertension, was slightly cyanotic.

In only 14 children were recurrent infections of the upper respiratory tract observed. In the adults there appeared to be no increase in tendency to infection.

Murmurs had been detected during the first year of life in only 10 cases. In 23 patients the murmur was discovered

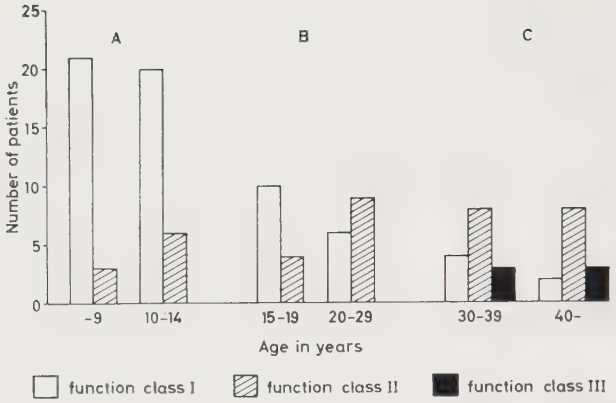


Fig. 3. No. of patients in different function classes according to age groups at time of operation.

during the pre-school years. In 43 patients the murmur was discovered during the school period, at an age of between 7 and 14 years. In 10 out of 28 patients in age group C the murmur was detected after the age of 30 years.

In consideration of the age distribution of the material, it was also of interest to know how the heart disease had been discovered. As shown in Table 4 the discovery was usually made during a routine examination at a Child Welfare Clinic or at school, or at mass radiography, an examination during pregnancy, or other routine health investigations. In 78 patients the heart disease was discovered at examinations of this type. In 24 patients a murmur had been heard during the investigation of another condition. Only 5 patients had sought medical advice for symptoms which could be related to heart disease.

Functional capacity and exercise tests

Function classes. The functional capacity of the patient was evaluated on the basis of the case-history data.

The *preoperative* function classes in relation to the age groups are given in Fig. 3. In age group A, 41 out of 50 children were completely free of symptoms (function class I). 9 patients were assigned to function class II because of increased exhaustibility and breathlessness on moderate effort. In age group B, consisting of 29 patients of ages 15—29 years, 16 of these patients were in function class I, and 13 in function class II. Out of 28 patients in age group C, only 6 were free of symptoms (function class I); 16 patients were in function class II, and 6 in function class III.

The functional reduction began at the age of about 20 years; 51 out of 64 patients below 20 years of age were in function class I, compared with only 12 out of 43 patients over this age.

At the *follow-up examination* a marked improvement of the subjective functional capacity was noted. Only 8 patients now qualified for function class II, one in age group A, 3 in age group B and 4 in age group C. One of these patients in function class II showed no change, and 3 patients in preoperative function class III showed improvement. 4 patients had

been subjectively free of symptoms preoperatively, but deteriorated, 3 of them due to postoperative cardiac rhythm disturbances and one woman due to an abnormal increase in weight.

Exercise tests. Exercise tests were performed mainly so as to allow comparison between the physical work capacity before and after operation, but also to obtain an idea of the relationship betwen subjective symptoms, and objective signs of functional reduction. Exercise tests were performed by 81 patients preoperatively and by 89 at the follow-up examination.

In 68 patients comparison was made between the preoperative and postoperative values of PWC_{170}, expressed in kpm/min per kg body weight (Fig. 4), but no significant difference was noted either in the children or adults.

Preoperatively, 11 patients in function class II were assessed as having a normal physical work capacity, and in 9 patients in function class I this was assessed as reduced. Since breathlessness was a common symptom, it was expected that patients with a reduced physical work capacity would have a higher than normal respiratory rate in relation to the work load. This was in fact shown in only 8 patients, for whom the exercise tests were discontinued at relatively low work loads because of a high respiratory rate. In these patients lung function tests gave values within the normal limits.

In 15 patients in function class II with reduced physical work capacity, there were signs of limitation of peripheral blood flow; after a short period at a low work load, when the pulse and respiration values were relatively high,

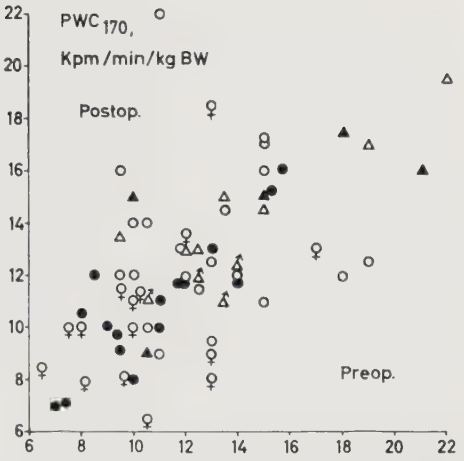


Fig. 4. Physical work capacity, expressed in kpm/min per kg body weight, before and after operation.

Circles represent women, triangles men; open symbols = children, filled symbols = patients in age group B. Circles with crosses, and triangles with arrows represent patients in age group C.

the patient was forced to discontinue the exercise test because of tiredness, especially of the legs. Muscular weakness, due, for example, to lack of training, may have been contributory.

Postoperatively, 18 patients in function class I were assessed as having a reduced physical work capacity.

In 22 patients who had been subjectively symptom-free preoperatively, there was a marked subjective improvement in the work capacity, but no objective functional change at the follow-up examination.

Other investigations

Blood. In all patients except three the preoperative values for red blood cells, haemoglobin, haematocrit and sedimentation rate lay within the normal limits,

according to the norm used at our laboratory (de Verdier and Killander, 1965); these exceptions were two children and one adult with somewhat low blood values indicating mild anaemia. At the follow-up examination the routine blood values were normal in all patients.

Urine analysis. Tests for protein and glucose, and sediment determination, were performed as routine, and the results were normal in all patients both preoperatively and at the follow-up examination.

The non-protein nitrogen was determined before and after the operation and was normal in all patients.

The *basal metabolic rate* was determined in all adult patients, with normal results. In no case was there any clinical sign of dysfunction of the thyroid gland, either before or after the operation.

Lung function tests. The normal values were calculated according to the norm used at this laboratory. The following variations from the mean values were considered normal: for MVV_f and VC± 20 %, for FEV % ± 8 % (see Hallén, 1964, for further references). 36 patients were examined preoperatively, including 6 children, and these results lay within the normal limits.

At the follow-up examination lung function tests were carried out in a further 10 patients, with normal results.

Electroencephalogram (EEG). EEG recordings were made preoperatively in 92 patients, and in 83 of them the results were evaluated as normal. In 3 children and 1 adult, the EEG was of a paroxysmal type. In 5 patients (3 children and 2 adults) other non-specific pathological changes were noted.

At the follow-up examination EEG recordings were made in 97 patients. The pathological changes recorded before the operation were still present. In 5 patients who had shown a normal EEG preoperatively, non-specific pathological changes were now seen, which in two cases appeared to be related to suspected postoperative cerebral air emboli; in the other three patients no definite explanation for the EEG change was found.

Discussion

The results of the preoperative height and weight determinations are in agreement with those of previous similar Scandinavian investigations of Kjellberg et al. (1959) and Davidsen (1960). Taussig (1947) pointed out that children with an atrial septal defect are often gracile, thin and underdeveloped, but according to Kjellberg et al. this feature is to be seen also in children with a large left-to-right shunt via a ventricular septal defect or a patent ductus arteriosus. Although only a few patients showed weight values outside the normal range limits (± SD), there was some tendency in the children towards low weights preoperatively. At the follow-up examination they showed a more normal distribution around the mean value. In some patients, however, the weight was lower than normal before operation as well as at the follow-up examination, in spite of a normal weight increase, and this would seem to indicate that in addition to haemodynamic factors other, for example constitutional factors may also

provide a reason for the slender body build which may sometimes be found in patients with an atrial septal defect.

It is to be expected that a congenital disease such as atrial septal defect of the secundum type, with its often rather mild physical manifestations, will be discovered relatively late in life. In many cases in the present series a murmur was heard on some occasion during school years, but was not regarded as a sign of organic heart disease, but was often "rediscovered" at a later examination or in connection with the onset of symptoms. The onset of the symptoms and the symptoms themselves differed somewhat in the present series from the descriptions usually given by other authors, including Bedford et al. (1957) and Davidsen (1960), but this may be explained by the fact that, with a few exceptions, this happened to be a series of haemodynamically uncomplicated secundum defects with mild symptoms and a late onset. Mild symptoms occurred in 44 out of 107 patients, and in only 6 cases were the symptoms so pronounced as to indicate function class III; together with the finding that the symptoms were seldom manifest before the age of 20 years, the present results are probably representative of the haemodynamically uncomplicated secundum defect.

When grading the functional capacity into function classes according to the degree of severity of the symptoms as reported in the case history, consideration must be taken of the possible presence of non-cardiac symptoms and also of cardiac symptoms which are not necessarily due primarily to the atrial septal defect but which arise rather from some secondary deterioration of the basic general condition. For example, if the patient has been aware of his murmur since childhood, and has often been advised to avoid undue effort (e.g. has been excused from gymnastics, etc.), this may result in a reduction of his general physical fitness and thus a lowering of his physical work capacity. This may be less pronounced in patients in whom an atrial septal defect is diagnosed during a routine examination at a more advanced age. At the same time it must be taken into account that patients with a congenital heart disease such as ASD sec may become so adapted to their condition that they consider themselves free from symptoms. With a functional improvement after the operation the patient may then realise the falsity of his previous assumption. Further, a subjective improvement after the operation, which is not accompanied by any objective change, may be a nonspecific expression of the reaction of the patient to successful surgery. No objective evaluation of the functional capacity after surgical repair of atrial septal defects appears to have been reported previously. In the present series there was a number of patients before as well as after the operation with a reduced physical work capacity, but preoperatively most of the patients had symptoms, while postoperatively the majority were subjectively symptom-free, and this shows the value of objective function tests in assessing the physical work capacity of the patient. After operation on an uncomplicated ASD sec, an improvement of the physical work capacity might be expected. This capacity is governed

mainly by the capacity of the circulatory system to transport oxygen (Sjöstrand 1956). In patients with a low physical work capacity preoperatively, due to reduced peripheral blood flow, probably resulting from lack of physical training, closure of the defect in uncomplicated cases should not *a priori* be followed by any change in the systemic circulation and therefore in the physical work capacity. This was analysed in the present series, and no significant change in the physical work capacity was noted after the operation. Jonsson et al. (1957) have demonstrated, further, that there is no relationship between magnitude of shunt and physical work capacity.

The ventilation capacity in those patients in whom this was tested lay within the normal limits, with no difference between the pre- and postoperative values. These patients also showed preoperatively only a slight raise in the systolic pressure in the pulmonary artery and a low pulmonary resistance at rest. On the other hand, in atrial septal defect with a high systolic pressure in the pulmonary artery, regardless of whether this was caused by a greatly increased pulmonary blood flow or a raised pulmonary resistance, Woolf (1963) found signs of low compliance and high nonelastic resistance as an explanation for the "excessive hyperventilation" on exercise, while Gazetopoulos and Davies (1966) found no relationship between different haemodynamic parameters and excessive ventilatory rate during exercise in patients with left-to-right shunts, but discuss the possibility of a relationship betwen tissue hypoxia and ventilatory response.

In order to evaluate any cerebral anoxic damage associated with the operation, electroencephalographic recordings were made before the operation and at the follow-up examination. None of the patients showed clinico-neurological signs of cerebral dysfunction at the follow-up examination. In three patients, for whom both the operation and the postoperative period were free of complications, newly manifest nonspecific pathological changes were seen, for which no definite explanation was found.

Summary

The growth and physical development in 66 patients below the age of 20 years is reported. In only a few patients did the preoperative values lay outside the ± 2 SD limits of variation for Swedish children, which is in agreement with previous findings. In the children, however, there was some tendency to low weights preoperatively, but at the follow-up examination a weight increase was noted, the deviation from the mean value diminishing significantly; this can be interpreted as a nonspecific sign of improvement in this age group.

The murmur was usually discovered at a routine examination during the preschool or school period. Only 5 of the 107 patients had sought medical advice for symptoms which could be related to the cardiac disorder.

Preoperatively, 44 patients had symptoms, 38 in function class II and 6 in function class III. The functional deterioration occurred after the age of 20 years. Reduction in physical work capacity, probably due to lack of physical

training, was noted as an average result preoperatively and was unchanged postoperatively. Postoperatively there was, however, subjective improvement in the work capacity, which may have been an expression of the general nonspecific reaction after the operation.

There was no postoperative change in the physical work capacity as expressed in PWC_{170}, compared with the preoperative values.

Lung function tests in 36 patients gave normal results both pre- and postoperatively.

No signs of cerebral anoxic damage were found by EEG or clinico-neurological routine examination after the operation.

CHAPTER V

Physical cardiac findings and chest roentgenogram before and after operation

Precordial palpation

Preoperatively there were palpatory signs of increased activity of the right ventricle in 76 patients. At the *postoperative* examination some normalization of these findings was observed, the right ventricular activity being considered increased in only 27 patients, 18 of whom were children. Obviously no close correlation between palpatory findings and haemodynamic conditions can be made, but the present results may indicate some relationship between the change in palpatory findings and the decreased load on the right ventricle.

Auscultation and phonocardiogram

The first heart sound was evaluated over the 4th left intercostal space, parasternally, and the second sound and systolic murmur over the pulmonary area (2nd and 3rd left intercostal spaces, parasternally). The diastolic extra sounds and murmurs were evaluated over the tricuspid area (4th left intercostal space, parasternally or midsternally). The second sound and systolic murmur were also evaluated during the more immediate postoperative period, at about 2 weeks after the operation. Separate evaluation of the aortic and pulmonary components of the second sound may be difficult. The criterion used for an accentuated pulmonary component was that its distribution over the precordium should be increased to regions outside the customary pulmonary area, especially if in such regions the pulmonary component was of greater amplitude than the aortic component.

First heart sound. Preoperatively, the first heart sound was considered to be louder than normal in 43 patients, with an approximately equal distribution between children and adults.

At the *follow-up* examination this heart sound was considered normal in all except 12 cases.

Second heart sound. Table 5 shows the results of evaluation of the second sound in the entire series before and also immediately after the operation and at the follow-up examination.

Before operation. On auscultation, constant splitting of the second sound was found in all cases, and accentuation of pulmonary component in all except 5.

On PCG recording the time interval between the aortic and pulmonary components of the second sound was found to be constant in all patients except 11, and was, on the average, 5.5 (3—8) centiseconds (csec). No difference was seen between the different age groups. In the 11 patients in whom the second sound varied with respiration, the interval variation between the sound components was less than 1 csec. The pulmonary component was accentuated in 60 patients.

After operation. In the immediate postoperative period auscultation showed the second sound to be still constantly split in 72 patients, and the pulmonary component was accentuated in 90 patients.

On PCG recording, however, the splitting was found to show some physiological variation in 45 patients. The interval between the sound components had decreased somewhat, compared with the preoperative findings, being 4.6 (2—7) csec, on the average with no difference between the age groups. The pulmonary component was accentuated in 36 patients.

At follow-up examination. On auscultation the second sound at the follow-up examination was variable in 64 patients and the pulmonary component was accentuated in 93 patients.

PCG recording, however, showed a definitely inconstant splitting of the second sound in 97 patients, where the time interval between the sound components varied by 1—2 csec. The time interval between the aortic and pulmonary components was now, on the average, 5.0 (3—8) csec. In 34 patients, including 18 children, the pulmonary component was accentuated.

Thus before the operation constant splitting of the second sound was registered in 96 of the 107 patients, while at the follow-up examination the splitting of the sound varied during the respiratory cycle by 1—2 csec in a similar number of cases. The relationship between the amplitudes of the sound components also varied. Of the 34 patients in whom a residual predominant pulmonary component was found at follow-up examination, 18 were children. PCG recording was superior to auscultation as regarded the evaluation of the amplitude of the sound components and the variations in time interval between the aortic and pulmonary components of the second sound.

Table 5. Second heart sound on PCG registration before and after operation and at follow-up examination. Time interval in csec between aortic (A_2) and pulmonary (P_2) components of the second heart sound on expiratory apnoea.

	Second heart sound			
	Split			
	constant	inconstant	Amplitude $P_2 > A_2$	Time interval
	No.	No.	No.	csec
Preop.	96	11	60	5.5 (3—8)
Postop.	62	45	36	4.6 (2—7)
Follow-up	10	97	34	5.0 (3—8)

Third heart sound. In 19 cases, including 13 children, a diastolic extra sound was heard.

This sound was always recorded together with a diastolic filling murmur in patients with a large left-to-right shunt, and was interpreted as a diastolic filling sound. This appeared to be absent after the operation.

Systolic murmurs. Table 6 shows the incidence of systolic murmurs heard on auscultation at the three examinations.

Before operation. In 73 patients the systolic murmur was of intensity grade III, with an equal distribution between

TABLE 6. Incidence of patients with systolic murmurs of different grades heard on auscultation before and after operation and at follow-up examination.

	Systolic heart murmur, grade				
	IV	III	II	I	0
Preop.	13	73	19	2	—
Postop.	—	3	40	41	23
Follow-up	—	2	38	57	10

children and adults. A systolic murmur of grade II was found in 19 patients, and of grade IV in 13 patients. In two adult patients a systolic murmur of grade I was heard.

After operation. After the operation the systolic murmur was attenuated, and in only 3 patients was it of intensity grade III. Systolic murmurs of grade II were heard in 40 patients, the majority being children. A low-pitched grade I systolic murmur was heard in 41 patients, while in 23 patients no murmur at all was heard .

At follow-up examination. At the follow-up examination a systolic murmur of grade III was heard in 2 patients. A systolic murmur of grade II was heard in 38 patients, this figure thus being essentially unchanged compared with the immediately postoperative findings. On the other hand a systolic murmur of grade I was now somewhat more frequent, being heard in 57 patients.

The PCG recording was in essential agreement with the auscultatory findings except in three patients, in whom murmurs of grade I were heard on auscultation but were not confirmed by PCG. Before and after operation, the murmur was of the early systolic ejection type, but postoperatively both the amplitude and intensity were lower, and the duration usually somewhat shorter.

Diastolic murmur, preoperative. The typical early mid-diastolic filling murmur was only heard before the operation, and then in 60 patients.

The PCG recording was in agreement preoperatively with the auscultatory findings regarding the distribution and intensity of the systolic murmur but on the other hand in 5 cases a diastolic murmur definitely heard on auscultation was not registered by PCG.

Systemic blood pressure

The arterial blood pressure was measured by the usual cuff method, with an aneroid manometer checked against a mercury column.

The mean preoperative value for children was 110/70 (range 95/60—130/85), and this value remained essentially unchanged after the operation. Two adult patients had arterial hypertension with systolic pressures of 185 and 200 mm Hg and diastolic pressures of 100 mm Hg. The mean preoperative value for adults was 135/80 (range 105/60—200/100), and this value remained essentially unchanged at the follow-up examination (140/85; range 110/65—200/100).

Chest roentgenogram

Since it is often difficult to evaluate the *heart configuration* in patients with atrial septal defects, no detailed analysis or gradation of the different findings was made.

Preoperatively it was noted, however, that 82 patients had distinct dilatation

Table 7. Distribution of patients according to heart size as determined by chest X-ray before and after operation.

Heart size			No.	
			Preop.	Postop.
Normal	Children	⩽350 ml/m² BSA	5	23
	Women	⩽450 »	14	31
	Men	⩽500 »	2	6
		Total	21	60
Slight enlargement	Children	>350—500 »	33	26
	Women	>450—600 »	19	6
	Men	>500—650 »	6	6
		Total	58	38
Moderate enlargement	Children	>500—650 »	10	1
	Women	>600—750 »	7	5
	Men	>650—800 »	4	—
		Total	21	6
Pronounced enlargement	Children	>650 »	2	—
	Women	>750 »	4	2
	Men	>800 »	1	1
		Total »	7	3

of the pulmonary artery and its central and peripheral branches. In 76 of these patients signs of enlargement of the right ventricle were seen, which in 36 cases were evaluated as pronounced. In 18 patients only moderate dilatation of the pulmonary artery was seen, and in 7 patients the configuration was considered to be normal.

At the *follow-up examination* a regression of the preoperatively increased dilatation of the central and peripheral branches of the pulmonary artery was seen. Residual dilatation of the main trunk of the pulmonary artery was observed in 81 patients; this dilatation was considered to be less pronounced than before the operation but more pronounced than the normal. In 26 patients the configuration was normal. Neither the age of the patient nor the length of time after operation appeared to influence the degree of residual dilatation of the main trunk of the pulmonary artery.

Heart volume. The results of the evaluation of the relative heart volume before the operation and at the follow-up examination are given in Table 7.

Preoperatively, the heart volume was normal in 21 patients. In 58 patients there was slight enlargement of the heart, in 21 patients moderate enlargement and in only 7 patients pronounced enlargement. Preoperatively the heart volume was, on the average, 448 (315—

800) ml/m² BSA in children, 491 (325—800) ml/m² BSA in young adults and 625 (400—1260) ml/m² BSA in older adults.

At the *follow-up examination* the corresponding values were 350 (240—510), 419 (260—760) and 554 (430—1260) ml/m² BSA. In the patients of all age groups the roentgenological heart volume was significantly (***) smaller postoperatively than preoperatively.

Sixty patients now showed a normal heart volume and 38 a slight residual cardiac enlargement. Only 9 patients had more advanced cardiac enlargement (6 moderate and 3 pronounced). In 1 child and 3 women with residual, moderate enlargement, this could be explained by postoperative cardiac rhythm disturbances, viz. an AV block II in three cases, and an AV block III in one case. In the other 2 cases no explanation was found for the absence of volume reduction 2 1/2 years, on the average, after the operation.

Three patients had residual pronounced cardiac enlargement at the follow-up examination. In these three patients the enlargement was probably an expression of irreversible dilatation due to myocardial damage, which had been caused preoperatively by pulmonary hypertension in one case and by myocarditis with mitral insufficiency in another case. The third patient had atrial fibrillation both pre- and postoperatively.

Discussion

The preoperative physical cardiac findings in this series of patients were in agreement with those usually described previously in uncomplicated atrial septal defect of the secundum type. The postoperative findings were as expected after a satisfactory operation. Postoperative findings have been described by Loogen & Toker (1961), among others, but the value of their findings in 100 surgically repaired secundum defects is limited somewhat by the fact that only 43 of the patients underwent recatheterization, 7 of whom had a residual shunt. The present material consisted of a haemodynamically uncomplicated uniform series of surgically corrected ASD sec, in which, at follow-up examination with heart catheterization, it was shown that the defect was completely closed.

After repair of an atrial septal defect, the excess volume load on the right heart and pulmonary circulation disappears instantly, while on the other hand structural restitution occurs gradually. As a result a flow murmur can be heard over the pulmonary region, caused by turbulent flow through a still somewhat dilated pulmonary artery. This means also that the second sound, partly for the same reason — reduced elasticity in the wall of the pulmonary artery (Jonsson, 1958) — is still extensively split but with some physiological variation, which can be explained by a decrease in the flow volume.

In this series of patients the total number of residual murmurs was essentially greater than that reported by Loogen & Toker (1961) and Reindell et al. (1962), while, on the other hand, the frequency of murmurs of grade II was essentially the same. However, a larger number of weak murmurs (grade I) were heard on auscultation.

Preoperatively, 21 patients showed a normal heart volume roentgenologically, while only 7 were considered to have a normal heart configuration. Dilatation of the pulmonary artery and increased vascularity of the lungs do not occur only in atrial septal defect, but these conditions without dilatation of the left atrium appear to constitute the most definite roentgenological finding.

Roentgenologically, compared with the preoperative findings reduced vascularity of the lungs was the first change observed after the operation, while on the other hand the main trunk of the pulmonary artery and right ventricle may return to normal gradually during the year immediately following surgery. Loogen & Toker (1961) found a residual cardiac enlargement in 34 %, usually in older patients. In the present series a slight residual cardiac enlargement was seen roentgenologically in 38 patients (35 %), of whom 26 were children. The large proportion of children can probably be explained by the fact that they were examined, on the average, sooner after the operation than the adults. At the routine examination 1 1/2 years, on the average, after recatheterization, only 2 children showed a residual slight cardiac enlargement, which in one of them could have been due partly to preoperative rheumatic carditis. In most cases, however, the pulmonary artery was somewhat dilated compared with normal conditions. The relationship between age, heart volume, left-to-right shunt and right ventricular pressure will be discussed in chapter VII.

Slight residual cardiac enlargement did not give rise, however, to any abnormal haemodynamic changes. In isolated cases with more pronounced enlargement after the operation, this was due either to newly acquired postoperative, or irreversible preoperative factors.

Summary

The physical findings before and after operation in this series were in agreement with previous findings in uncomplicated ASD sec.

The second heart sound was preoperatively constantly split and postoperatively it was inconstantly split in 90 % of the patients, but the average time interval between the sound components was practically unchanged, viz. 5—6 csec.

Systolic murmurs were heard postoperatively in all except 10 patients, but were of a lower grade than preoperatively and can be explained by turbulent flow in the dilated pulmonary artery.

All patients except 2 adults had a normal arterial blood pressure before the operation, and this remained unchanged postoperatively.

The heart configuration was pathological preoperatively in all except 7 patients, with dilatation of the pulmonary artery and its central and peripheral branches. Signs of hypertrophy of the right ventricle were seen in 76 cases. Postoperatively the vascularity of the lungs was reduced compared with preoperatively, while the dilatation of the main trunk of the pulmonary artery persisted for a long period and was seen in 81 of the 107 patients at the follow-up examination, though to a less pronounced extent than preoperatively.

Preoperatively 21 patients had a normal heart volume, 58 patients showed slight cardiac enlargement, 21 moderate enlargement and 7 pronounced enlargement. At the follow-up examination 60 patients had a normal heart volume, 38 patients showed slight cardiac enlargement and in 9 patients the enlargement was more pronounced. There was a significant (***) postoperative reduction of the heart volume in the different age groups. The children, in particular, showed a residual slight enlargement, which may be explained by the fact that in this group the observation period was shorter than in the adults; at a further follow-up examination 18 months, on the average, after recatheterization, the heart volume was normal in all children except three. No abnormal haemodynamic changes were noted in association with residual slight enlargement. In the isolated cases with more pronounced cardiac enlargement postoperatively, this was due either to newly acquired postoperative, or irreversible preoperative conditions.

CHAPTER VI

Electrocardiographic findings before and after operation

ECG studies were made in all 107 patients both preoperatively and at the follow-up examination, with regard to rate and rhythm, the nature and duration of the P wave and the QRS complex, the direction of the mean QRS axis in the frontal plane, and T wave abnormalities. In addition, the ECG was studied with respect to arrhythmia and S-T and T changes during the immediate postoperative period.

Heart rate and rhythm

Preoperatively the heart rate was, on the average, 93 (70—150) beats per minute in the children and 78 (55—115) in the adults. In 20 children and 5 adults the heart rate was more than 100 beats per minute.

At the *follow-up* examination the corresponding figures were 81 (45—130) and 71 (40—120), respectively. Five children and 2 adults now had a heart rate of more than 100 beats per minute.

Preoperatively all patients showed *sinus rhythm,* with the exception of one 62-year old woman with atrial fibrillation with a normal ventricular rate.

At the *follow-up* examination 5 patients showed residual postoperative arrhythmia. Three patients had an A-V block II; in two of these patients this persisted at a later examination, but in the third patient, a 12-year old girl, sinus rhythm was recorded 4 years after the operation. One patient had a postoperative A-V block III which required pacemaker therapy, and another patient showed therapy-resistant atrial fibrillation which had been present preoperatively.

Cardiac rhythm disturbance during the immediate postoperative period. During the entire postoperative period up to the follow-up examination, 50 patients showed sinus rhythm, the incidence being somewhat higher in young than in older patients.

In 30 patients, relatively regular supraventricular rhythm was noted initially, and on an average of 2.3 days after the operation this changed to regular sinus rhythm.

In 6 patients, sinus rhythm was recorded during the first 24 hours postoperatively, and after an average of 4.1 days this changed to supraventricular rhythm, but 3.5 days later sinus rhythm was again noted in these patients.

Thus 86 of the 107 patients had regular sinus rhythm 8 days after the operation, while 21 patients showed residual postoperative arrythmia. Of these, 12 patients (5 children, and 7 adults) had regular supraventricular rhythm, which changed to sinus rhythm after an average of 29 days. 5 patients (2 children and 3 adults) showed an A-V block

II. In 3 of these patients sinus rhythm was recorded 3 weeks, 4 months and 4 years, respectively, after the operation, but in the other 2 patients this block is still present. One 42-year old woman had a postoperative A-V block III which necessitated pacemaker therapy. Two patients had atrial fibrillation, which after medication altered to sinus rhythm 8 weeks and 12 weeks, respectively, after the operation. In the patient who had atrial fibrillation preoperatively, repeated attempts to regularize the residual postoperative fibrillation, both by medication and cardioversion, were unsuccessful.

A detailed study of different data obtained during the operation under hypothermia was made in an attempt to determine the reason for the immediate postoperative arrhythmias, but these showed no correlation with the operation time, time of circulatory arrest, cooling or rewarming time, or with the acid base values. In association with inflow occlusion all patients showed cardiac rhythm disturbances of varying types, usually nodal rhythm with ectopic ventricular beats, but there was no apparent relationship between these disturbances and the residual arrhythmias. A tendency was observed, however, to immediate postoperative arrhythmia in patients with large central defects, and, especially, those with low defects, where traumatic effects on the atrio-ventricular nodal region were often unavoidable.

P waves

Preoperatively the amplitude of the P wave, measured in mm (1 millivolt, mV = 10 mm) in *lead II,* was, on the average, 1.5 in the children and 1.2 in the adults.

Postoperatively the corresponding values were 1.2 and 1.1 mm respectively. Only in the children was there a significant difference (***) between the pre- and postoperative values.

The *amplitude* of the P wave in *lead* V_1 was, on the average, somewhat lower both pre- and postoperatively (1.0 and 0.6 mm, respectively), than in lead II, but the postoperative amplitude reduction in lead V_1 was more pronounced (***).

Preoperatively the duration of the P wave in *lead II* was, on the average, 7.5 csec in the children and 8.7 in the adults.

Postoperatively the corresponding values were 6.5 and 7.7 csec, respectively. The difference between the pre- and postoperative values were significant for the children (***) and for the adults (**).

Only in 6 patients were preoperative signs of atrial hypertrophy observed in lead II, with a P wave amplitude of 2.5 mm or more or a P wave duration of 12 csec or more.

P-R interval. Preoperatively the P-R interval was, on the average, 15.6 csec, and at the *follow-up* examination this was significantly shorter (**), viz. 14.2 csec. The P-R interval was longer than 20 csec in 13 patients (including 10 in age group C) preoperatively and in 9 patients at the follow-up examination. On the average, the adult patients showed a somewhat longer P-R interval than the children.

Table 8. Distribution of preoperative QRS complex in lead V_1 in relation to age group, heart size, shunt group and right ventricular systolic pressure.

	R		rSR′		rsr′s′		rS	
Age group	No.	%	No.	%	No.	%	No.	%
A	14	61	19	40	9	47	8	53
B	5	22	12	25	7	37	5	34
C	4	17	17	35	3	16	2	13
Total	23	100	48	100	19	100	15	100

	R		rSR′		rsr′s′		rS	
Heart size	No.	%	No.	%	No.	%	No.	%
Normal	3	14	6	13	4	21	4	27
Slight enlargement	16	73	25	54	8	42	8	53
Moderate enlargement	2	9	11	24	6	31	2	13
Pronounced enlargement	1	4	4	9	1	6	1	7
Total	22	100	46	100	19	100	15	100

	R		rSR′		rsr′s′		rS	
Shunt group	No.	%	No.	%	No.	%	No.	%
1	4	18	6	13	4	21	3	20
2	11	50	17	37	8	42	8	53
3	7	32	23	50	7	37	4	27
Total	22	100	46	100	19	100	15	100

	R		rSR′		rsr′s′		rS	
RV systolic pressure mm Hg	No.	%	No.	%	No.	%	No.	%
<30	8	36	20	43	7	38	6	40
⩾30	14	64	26	57	12	62	9	60
Total	22	100	46	100	19	100	15	100

QRS complex

In spite of large variations in the QRS complex in lead V_1, it was possible in principle to classify the different types into the four QRS patterns shown in

Fig. 5. Configuration of QRS complex in lead V.

Table 9. ECG patterns in lead V_1 before and after operation

		Before operation				
		R	rSR′	rsr′s′	rS	No. of patients
After operation	R	11	2	—	—	13
	rSR′	5	33	5	1	44
	rsr′s′	1	9	6	—	16
	rS	6	4	8	14	32
No. of patients		23	48	19	15	105

Fig. 5. The preoperative QRS pattern in V_1 in relation to age group, heart size, shunt group and right ventricular systolic pressure can be seen in Table 8. For two patients no ECG recording in V_1 was made preoperatively.

Preoperatively the R pattern was seen more frequently in the children (age group A) than in the adults (age groups B and C), while the rSR' pattern was somewhat more frequent among the adults. Of the two other QRS patterns, the frequency was approximately equal in the children and adults.

All four types of complex showed the greatest frequency among patients with slight cardiac enlargement, and in addition the frequency of these types was greater in patients with normal heart size than in those with pronounced enlargement.

Further, all types of QRS complex, except the rSR' pattern, were seen most often in shunt group 2, while the rSR' pattern was somewhat more frequent in shunt group 3.

The rSR' pattern was of approximately equal frequency in patients with normal as in those with raised systolic right ventricular pressures, while the other QRS patterns showed a greater frequency in patients in whom this pressure was raised.

Only in children was a significant correlation (*) seen between shunt size and the amplitude of the R wave in lead V_1. At the follow-up examination no significant correlation was found, however, between shunt reduction and reduction of the amplitude of the R wave, either in the children or the adults.

R pattern. This is consistent with right ventricular hypertrophy, and the qR and rR' complexes have also been included in this type. *Preoperatively* 23 patients showed this pattern in V_1. In 10 patients (4 children and 6 adults) a qR complex was seen.

Postoperatively the ECG pattern remained unchanged in 11 patients of this group, which can be seen in Table 9.

rSR' pattern. This complex, which is described as characteristic of atrial septal defect, is considered to be due to hypertrophy and/or dilatation of the right ventricular outflow tract rather than to right intraventricular conduction delay, i. e. partial right bundle-branch block (Pryor et al. 1959).

Preoperatively 48 patients showed this complex in V_1.

Postoperatively this type of complex persisted in 33 patients (14 children and 19 adults) and, as seen in Table 9, 2 of the patients now showed an R complex, 9 an rsr's' complex and 4 a normal rS complex.

In the 33 patients in whom the QRS complex was unchanged, the amplitude of R' was, on the average, 10.9 mm preoperatively and 7.0 mm, i. e. significantly lower (***) postoperatively. The reduction of the R' amplitude was more pronounced in the children than in the adults.

The ventricular activation time (VAT) in V_1 in these patients was 6.8 csec preoperatively and 6.3 csec, i. e. significantly shorter (*) postoperatively.

rsr's' pattern. This QRS complex, which differs from the more typical rSR' pattern mainly by its generally lower amplitude and the terminal s' wave, is probably also, however, an expression of right ventricular outflow tract hypertrophy; this pattern was observed *preoperatively* in 19 patients.

The rsr's' pattern persisted *postoperatively* in 6 patients, while in 5 patients a more typical rSR' complex, and in 8 patients a normal rS complex, were recorded.

rS pattern. This pattern, which is normal in V_1, was seen *preoperatively* in 15 patients.

Postoperatively the pattern remained unchanged in all except one patient.

Altogether, 64 patients had the same type of QRS complex postoperatively as preoperatively of which 50 were abnormal. 22 patients had different types of abnormal QRS pattern on the two occasions. In 18 patients newly acquired normal QRS complexes of the rS type were observed.

The amplitude of R in V_1 in those patients who did not exhibit the rSR' pattern either pre- or postoperatively was, on the average, 6.9 mm preoperatively and 4.6 mm, i. e. significantly lower (***) postoperatively, the decrease in R wave amplitude being most pronounced in patients with an R complex. On the other hand, no significant change was seen in VAT, which in these 72 patients was, on the average, 3.9 csec preoperatively and 3.2 csec postoperatively.

Preoperatively 70 patients showed a QRS complex of type Rs in *lead* V_5, and in 33 patients this complex was of the qRs type. The amplitude of the R wave in these complexes was, on the average, 14.4 mm.

Postoperatively 55 patients showed the Rs pattern, and 41 patients a pattern of the qRs type, with an average R wave amplitude of 18.1 mm, this being significantly higher (***) than preoperatively. The QRS duration in lead V_5 was, on the average, 1.0 csec shorter postoperatively than preoperatively, which was due to a significant (*) reduction of the duration of the S wave from an average of 4.2 to 3.3 csec.

QRS axis. Preoperatively, the mean QRS axis in the frontal plane was 81° in the children, and 89° in the adults, and the corresponding postoperative values were 75° and 71°, respectively.

The *postoperative* change of the mean QRS axis towards the left was significant in the adults (***) and in the children (*).

Preoperatively, only 14 patients (5 children and 9 adults) had a definite right axis deviation (more than + 110°), and this remained unchanged after the operation in 6 patients. No definite left axis deviation was observed, but preoperatively 4 patients showed a mean QRS axis of between 0° and 30°, and this was seen in 5 patients postoperatively. In cases of complete right bundle-branch block, only the first 7 csec of the QRS complex were used for calculation of the mean QRS axis.

QRS duration. Preoperatively the QRS duration in lead II was 8.7 csec in the children, and 9.4 csec in the adults.

Postoperatively there was no significant difference in the children (8.3 csec), but significant differences were noted in the adults (**), where the value was 8.5 csec.

The QRS duration was 10 csec or shorter in 92 patients preoperatively, and in 96 patients postoperatively. A QRS duration of 11 csec was observed in 7 patients preoperatively and in 5 patients postoperatively. A complete right bundle-branch block with a QRS duration of 12 csec or more was found preoperatively in 6 adult patients, in 4 of whom this persisted postoperatively.

T waves

The most pronounced T wave change occurred in the *immediate postoperative period.* On the day of operation the T wave amplitude was estimated in lead II in 49 patients and was, on the average, 1.9 mm; in 44 of these patients the S-T segment was considered normal, and in the remaining 5 somewhat elevated. On the first day after the operation a significant change was seen (***), the T wave amplitude now being 2.9 mm, on the average, and the S-T segment initially elevated in 74 out of 100 patients in lead II. This pattern persisted on the second day, but a gradual depression of S-T segment and the T wave was then seen up to the sixth day after the operation, by which time its amplitude was 0.8 mm and the S-T segment normal in 79 out of 92 patients.

During the first few weeks postoperatively a pronounced change in S-T and T was seen in the precordial leads, with depression of the S-T segment and flattening or inversion of the T wave. Two weeks, on the average, postoperatively, 59 patients still showed a negative or pathologically low T wave in lead V_5, with an approximately equal incidence in the children and adults.

At the follow-up examination the T wave amplitude in lead II was, on the average, 2.6 mm, thus showing no change from the preoperative value (2.4 mm). On the other hand, a pathologically low or negative T wave was observed in precordial leads V_1—V_4 in 42 patients (21 children and 21 adults), and in lead V_5 in 13 patients. Thirty of these 42 patients performed exercise tests postoperatively. In half of them the T wave, which was inverted at rest, showed some normalization in the standing position during the orthostatic test, and on deep inspiration. In all patients the T wave over the precordium gradually became normal with increasing work loads. This is an ECG reaction which may be seen in patients with previous

perimyocardial damage, and it has therefore been called "status post myocardial lesion" (Areskog and Hallén, 1964).

Discussion

The incidence of atrial fibrillation in ASD sec varies, but according to Wood (1962), who has discussed the haemodynamic effects and prognostic importance of atrial fibrillation in this condition, it is correlated particularly with age. Thus in the present series, of which only 4 patients were above 50 years of age, it was not surprising to find only one patient with atrial fibrillation — the oldest patient. In this patient the fibrillation was still resistant to therapy after the operation, and, together with pronounced cardiac enlargement, as seen roentgenologically, it probably expressed an irreversible myocardial lesion.

In three patients with residual postoperative arrhythmia of the high-grade A-V block type, the long-term prognosis is uncertain and in patients with uncomplicated ASD sec, a postoperative high grade A-V block is a complication which may worsen the outlook considerably, compared with the preoperative prognosis.

The postoperative arrhythmia in atrial septal defect is considered to be due to surgical trauma; according to Popper et al. (1962) the manipulations especially in the vicinity of the A-V node have an arrhythmia-inducing effect, and these authors state that apart from such factors the incidence of arrhythmia is only influenced by age.

In the present series 57 patients (53 %) showed arrhythmia at some time during the first week postoperatively. This is a rather higher figure than that of Popper et al. (1962), who found a total arrhythmia frequency of 43 % among a series of 126 secundum defects; in their patients, however, extracorporeal circulation was used, and from this aspect the two series are not entirely comparable. As in Popper's series, in which the patients were, on the average, somewhat younger, the incidence of arrhythmia in the present series increased with age.

The immediate postoperative supraventricular arrhythmia was, in most cases, of nodal origin. Since this arrhythmia was regular and of normal frequency, it caused the patient no discomfort. This arrhythmia, which can be caused by temporary oedema in the atrio-ventricular nodal region (Gomez et al. 1962), appeared to change to sinus rhythm spontaneously regardless of whether the patient received digitalis or not. Digitalis medication was not given as a routine preoperatively.

Serious postoperative arrhythmias in ASD sec have been described by, among others, Sellors (1961) and Derra et al. (1965). Derra et al. reported 2 cases of total A-V block among a series of 700 surgically repaired secundum defects; these two patients showed spontaneous regression within 2 months of the operation, however.

Especially in the adults, postoperative arrhythmia often prolonged the period of hospitalization considerably, and the increasing risk of arrythmia in ASD sec with advancing age, both with and without operation, indicates early surgery.

The preoperative ECG changes in ASD sec have been discussed greatly, especially as regards the correlation between ECG pattern and haemodynamics, and the aetiology of the typical rSR' complex in lead V_1. Pryor, Woodward and Blount (1959), in a study of 100 surgically closed secundum defects, found no applicable correlation between the QRS axis or height of R' in lead V_1 and either the pulmonary arterial pressure, total pulmonary resistance or pulmonary flow. A lack of correlation between ECG and haemodynamics has also been shown by Walker et al. (1955) and Barboza et al. (1958), *inter alia,* but De Oliveira and Zimmerman (1958) and Lee and Scherlis (1962), on the other hand, found some correlation between the QRS pattern in lead V_1 and the magnitude of the left-to-right shunt. In the present series, however, a significant correlation (*) between shunt size and the amplitude of the R wave in lead V_1 was seen only in children. At the follow-up examination no significant correlation was found between shunt reduction and reduction of the amplitude of the R wave, either in the children or the adults.

Cabrera and Monroy (1952) and Sodi-Pallares and Marsico (1955) considered that incomplete right bundle-branch block (IRBBB) in atrial septal defect was due to diastolic overloading of the right ventricle, while, on the contrary, Walker et al. (1956), Blount et al. (1957), Silverblatt et al. (1957) and, in particular De Oliveira and Zimmerman (1958) did not regard IRBBB as representing conduction delay in the right branch, but rather the presence of anatomical right ventricular dilatation and/or selective hypertrophy of the right ventricular outflow tract (crista supraventricularis), resulting in delayed activation of this tract. Both groups of authors considered, however, that right ventricular dilatation rather than right ventricular hypertrophy was typical in ASD patients with large left-to-right shunts and essentially normal right ventricular pressures.

The preoperative ECG changes in this series agreed in the main with those described in uncomplicated ASD sec by Pryor et al. (1959) and Loogen et al. (1961), among others.

After closure of an atrial septal defect, the diastolic overloading of the right ventricle disappears. The dilatation of the right ventricle decreases, as also does the hypertrophy in the right ventricular outflow tract. As a result the amplitude of the R wave in lead V_1 is reduced, and the mean QRS axis changes towards the left (Davies et al. 1960, Loogen et al. 1961). The regression of the preoperative ECG abnormalities is considered to indicate that the rSR' pattern in lead V_1 is caused by dilatation and/or hypertrophy rather than intraventricular conduction delay, since this can hardly be affected by the operation (De Oliveira and Zimmerman 1958, Davies et al. 1960). The P wave also decreases in both amplitude and duration after the operation (Sánchez-Cascos et al. 1963).

In the present series only six patients showed definite signs of atrial hypertrophy, which seems a low figure in view of the previous finding of a frequency up to 30 % in ASD sec (Sánchez-Cascos et al. 1963). Only among the children were

significant (***) changes observed in the amplitude and duration of the P wave in lead II; among the adults no change in amplitude was seen, but the duration was significantly (**) shorter. The postoperative decrease in the P wave must be an expression of flow reduction in the right atrium, even though no relationship was found preoperatively between shunt size and P wave pattern in lead II or V_1.

On comparing the pre- and postoperative QRS complexes, it was found that the QRS pattern in V_1 was the same on both occasions in no fewer than 64 patients, and in 50 of the cases this pattern was considered to be pathological. Postoperatively, a tendency towards normalization of the QRS pattern in V_1 was observed, but newly acquired normal QRS complexes of the rS type with an R:S ratio of less than 1 were seen in only 18 patients. Thus even though in most cases the *type* of QRS pattern remained unchanged, the *degree* of abnormality had decreased, especially as regards the amplitude of R or R' in lead V_1. In the 33 patients with the same characteristic "secundum complex" of the rSR' type in V_1 pre- and postoperatively, the activation time was only almost significantly shorter (*) postoperatively than preoperatively, while the amplitude was highly significantly lower (***). This may indicate that in these cases the amplitude reduction corresponded to regression of the hypertrophy and/or dilatation in the right ventricular outflow tract, while, on the other hand, a residual QRS pattern with a split complex may point to a congenital abnormality in the right bundle branch. This also corresponds to changes over the left ventricle (lead V_5), where a more pronounced increase (***) of the R wave amplitude was seen, as a sign of increased left ventricular activity, while, on the other hand, the reduction of the preoperatively wide S wave, probably caused by right ventricular conduction delay, was less pronounced (*).

A postoperative pathological QRS complex in V_1 differing more in degree than in type from the preoperative pattern was not thus an expression of a residual shunt, even though in some isolated cases the reduction in amplitude of the R wave was not especially pronounced.

Elevation of the S-T segment and inversion of the T wave in the immediate postoperative period are usually seen after open heart surgery (Areskog and Hallén, 1964). The S-T segment becomes normal after about a week, while the T wave change in the precordial leads may persist for a very long time. In the present series, at the follow-up examination pathological T wave changes were recorded in precordial leads V_1—V_4 in 42 patients and in lead V_5 in 13 patients. These T wave abnormalities, probably caused by perimyocardial disturbances during the operation, were of the "status post myocardial lesion" type, and gradually became normal during exercise tests. Similar types of ECG reactions with normalization of negative T waves during and after exercise have been described in myocardial lesions caused by infarction (Stokes 1946, Söderholm et al. 1962, Areskog and Hallén 1964) and in cardiomyopathy in Friedreich's ataxia (Thorén 1964),

and occur after open heart surgery not only in ASD sec but also in other cases. In approximately half of the patients in the present series some normalization of the T wave was observed on deep inspiration. A similar ECG response in healthy persons has been described by Blackman and Kuskin (1964), who considered that such a change in the T wave could be explained by the change in position of the heart during deep inspiration. In a number of cases where the part of the left lung covering the anterior region of the heart (the "cardiac notch") was poorly ventilated, Blackman and Kuskin recorded T waves, in leads V_2—V_4, of the type also seen in direct epicardial recording. On deep inspiration the distance between the heart and the thoracic wall is increased by the air-filled lung, which is a poor conductor of electrical currents, and the T wave amplitude changes.

In cases of surgically repaired ASD sec there is no definite reason to assume that the normalization of the T wave during exercise is due to changes in the myocardial metabolism or improved coronary perfusion resulting from vasodilatation, as has been discussed in connection with S-T and T alteration during exercise after myocardial infarcts. Hyperactivity of the sympathetic nervous system may explain depression and/or inversion of the T wave, which changes can be normalized by the use of ganglia-blocking media (Linderholm et al. 1962, Thorén 1964). This was not tested in the present series. After a thoracotomy the occurrence of small pleural adhesions can probably be assumed, which could make air filling of the "cardiac notch" difficult, and contribute to the occurrence of T wave changes especially in those cases where some normalization of the T wave on deep inspiration has been observed. These postoperative T wave abnormalities, which may thus be caused by a vegetative or functional mechanism, are considered to be benign in character, and are not to be regarded as unfavourable.

Summary

ECG studies were made on 107 patients with ASD sec before and after operation. Preoperatively, one patient showed atrial fibrillation. Postoperative arrhythmia occurred in 57 patients but 8 days after the operation this was observed in only 21 patients. A tendency to immediate postoperative arrythmia was seen especially in patients with large, low ASD sec. Five patients showed arrhythmia at the follow-up examination, but only 3 patients at a later examination; two of these three patients had an A-V block II, and the third an A-V block III, the latter requiring pacemaker therapy.

No relationship was found between shunt magnitude and the duration of amplitude of the P wave. Only 6 patients showed preoperative signs of atrial hypertrophy.

The preoperative ECG findings in this series were of the type usually described in ASD sec. In lead V_1 four principal types of QRS complex were distinguished. 50 patients showed the same pathological QRS complex postoperatively as preoperatively, this being of the "ASD sec" type, with an rSR' pattern, in 33 of these patients. The QRS

complex was evaluated as normal in 15 patients preoperatively and 32 patients postoperatively. In this series a significant correlation (*) between shunt size and the amplitude of the R wave in lead V_1 was seen only in children. At the follow-up examination, however, no significant correlation was found between shunt reduction and reduction of the amplitude of the R wave, either in the children or the adults.

Preoperatively only 14 patients showed a definite right axis deviation (more than + 110°). No definite left axis deviation (less than —30°) was seen. The postoperative change of the mean QRS axis towards the left was more marked in the adults than in the children.

Postoperatively the QRS duration was shorter in the adults but, on the average, unchanged in the children. Complete right bundle branch block with a QRS duration of 12 csec or more occurred preoperatively in 6 adult patients.

During the immediate postoperative period the S-T segment and T wave showed changes of the type usually seen in pericarditis. At the follow-up examination there was a residual pathological T wave in lead V_4 in 42 patients. In 30 patients who performed work tests, normalization of the T wave, which at rest was inversed, was observed during and after exercise. The reason for this "status post myocardial lesion" reaction is discussed and is considered to be of no functional importance. This pathological T wave at rest though observed for a long period after the operation, should not thus be regarded as unfavourable.

CHAPTER VII

Haemodynamic findings at rest before and after operation in 107 patients

TABLE 10. Preoperative observations during heart catheterization at rest in 107 cases with ASD sec.

Age groups and sex	Characteristic	Oxygen saturation per cent						Pressures, mm Hg				
								RA		RV		
		No.	LA	No.	PA	No.	SVC	No.	M	No.	S	D
A Girls	mean	25	96	31	83	31	67	31	4.0	31	33	2.5
Boys	»	16	96	19	87	19	66	19	4.4	19	29	3.2
Total	»	41	96	50	84	50	67	50	4.1	50	31	2.7
	min.		91		68		50		1		16	0
	max.		100		93		78		10		46	8
B Women	mean	15	97	21	85	22	63	21	4.0	22	33	3.4
Men	»	5	98	6	84	7	69	7	3.4	7	32	1.4
Total	»	20	97	27	85	29	65	28	3.9	29	33	2.9
	min.		97		80		55		—0.5		20	0
	max.		100		90		75		8		64	9
C Women	mean	8	95	20	85	18	64	21	2.5	21	33	3.2
Men	»	2	97	6	84	6	63	6	3.3	5	33	2.0
Total	»	10	95	26	85	24	63	27	2.7	26	33	3.0
	min.		90		78		56		—1		22	0
	max.		99		91		81		8		87	7
A+B+C												
Women	mean	48	96	72	84	71	65	73	3.6	74	33	3.0
Men	»	23	96	31	85	32	66	32	4.0	31	31	2.6
Total	»	71	96	103	84	103	65	105	3.7	105	32	2.8
	min.		90		68		50		—1		16	0
	max.		100		93		81		10		87	9
	SD		2.4		4.2		5.9		6.2		10.1	2.5
	SE		0.3		0.4		0.6		0.6		1.0	0.2

Age group A: Children up to 15 years.
B: Women and men 15—29 years
C: Women and men 30 years or more
SVC = superior vena cava
RA = right atrium
RV = right ventricle
PA = pulmonary artery

Comparisons were made between the results obtained on catheterization before operation and at the follow-up examination in the entire series of 107 patients, with respect to oxygen saturation and pressure at rest. The magnitude of the left-to-right shunt, expressed approximately as per cent of the pulmonary blood flow, was evaluated in relation to age, systolic right ventricular pressure and relative heart volume.

The results obtained on cardiac catheterization at rest before operation and at the follow-up examination are

PA				PCV		LA		LV			Left to right shunt per cent of pulm. blood flow	
No.	S	D	M	No.	M	No.	M	No.	S	D	No.	
30	26	10	17	26	7.2	26	5.1	17	97	4.7	31	56
19	25	9	16	17	7.4	16	5.6	11	98	5.2	19	65
49	25	9	17	43	7.3	42	5.3	28	98	4.9	50	59
	11	5	8		3		1		80	0		30
	50	24	40		12		11		150	9		86
22	25	9	15	18	6.5	16	5.9	7	101	5.9	22	62
7	25	8	14	5	6.2	5	4.0	2	105	2.0	7	54
29	25	9	15	23	6.4	21	5.4	9	102	4.9	29	60
	16	4	8		1		1		85	0		37
	50	25	30		12		9		130	6		81
21	28	10	17	17	4.5	10	4.5	8	117	5.9	20	65
6	31	9	15	5	6.2	3	3.7	2	112	5.5	6	64
27	29	10	16	22	4.8	13	4.3	10	117	5.8	26	65
	14	4	7		1		1		105	1		33
	80	25	40		8		10		140	10		87
73	26	9	16	61	6.2	52	5.3	32	103	5.3	73	60
32	26	9	15	27	7.0	24	5.0	15	101	4.7	32	62
105	26	9	16	88	6.4	76	5.2	47	103	5.1	105	61
	11	4	7		1		1		80	0		30
	80	25	40		12		11		150	10		87
	9.0	3.3	4.9		2.5		2.3		18.7	3.5		14.6
	0.9	0.3	0.5		0.3		0.3		2.8	0.3		1.4

PCV = pulmonary capillary venous pressure
LA = left atrium
LV = left ventricle
S = systolic pressure
D = diastolic pressure
M = mean pressure

Table 11. Postoperative observations during heart catheterization at rest in 107 cases with ASD sec.

Age groups and sex	Characteristic	Oxygen saturation per cent				Pressures, mm Hg	
						RA	
		No.	PA	No.	SVC	No.	M
A Girls	mean	30	70	31	69	31	2.7
Boys	»	19	71	19	69	19	2.7
Total	»	49	70	50	69	50	2.7
	min.		60		60		0
	max.		78		79		7
B Women	mean	18	72	17	69	22	1.7
Men	»	6	72	6	73	7	1.0
Total	»	24	72	23	70	29	1.5
	min.		64		60		—2
	max.		77		78		6
C Women	mean	21	69	20	68	22	1.4
Men	»	6	70	6	68	6	1.6
Total	»	27	69	26	68	28	1.5
	min.		58		53		—1
	max.		77		75		6
A+B+C							
Women	mean	69	70	68	69	75	2.0
Men	»	31	71	31	70	32	2.1
Total	»	100	70	99	69	107	2.0
	min.		58		53		—2
	max.		78		79		7
	SD		4.2		4.5		2.0
	SE		0.4		0.4		0.2

summarized in Tables 10 and 11 and Figures 6—8. Some individual values, either preoperative or for the follow-up examination were not obtainable, and for this reason the number of values sometimes varies in the different tables and figures.

Oxygen saturation

Left atrium. In 71 patients the oxygen saturation in the left atrium was recorded, the value obtained being, on the average, 96 %. In 3 patients the value was below normal; 2 patients with a value of 90 % were found on operation to have large, low defects with prerequisite conditions for a right-to-left shunt. These patients had no pulmonary hypertension nor cyanosis. In the third patient the oxygen saturation was 90 % in the left atrium, brachial artery and pulmonary vein. This patient also showed moderately pronounced pulmonary hypertension.

Superior vena cava (Fig. 6). *Preoperatively* the oxygen saturation in the superior vena cava was, on the average, 65 %. In 18 patients with anomalous

Abbrevations as in Table 10.

RV			PA				PCV	
No.	S	D	No.	S	D	M	No.	M
31	24	2.4	31	22	8	14	23	7.2
19	24	2.4	19	23	10	15	18	7.7
50	24	2.4	50	22	9	15	41	7.4
	13	0		12	3	10		2
	37	9		37	16	26		13
22	23	1.6	22	21	7	12	22	5.7
7	19	1.7	7	17	7	10	7	5.3
29	22	1.6	29	20	7	11	29	5.6
	10	—4		10	2	7		1
	50	8		40	15	27		12
20	24	3.1	20	24	9	13	18	5.6
6	24	2.3	5	23	7	12	4	4.0
26	24	2.9	25	24	8	13	22	5.3
	18	0		14	3	8		0
	45	8		35	18	22		12
73	24	2.4	73	22	8	13	63	6.4
32	23	2.3	31	21	8	13	29	6.6
105	24	2.3	104	22	8	13	92	6.5
	10	—4		10	2	7		0
	50	9		40	18	27		13
	6.4	2.3		6.2	3.2	4.3		3.2
	0.6	0.2		0.6	0.3	0.4		0.3

venous return to the superior vena cava, the saturation values were obtained above the entrance of the pulmonary veins, and these were found to lie within the normal range in all cases except one.

At *recatheterization* the oxygen saturation in the superior vena cava was, on the average, 69 %; this was significantly (***) higher than before the operation.

Pulmonary artery (Fig. 7). *Preoperatively* the oxygen saturation in the pulmonary artery was, on the average, 84 %, and varied between 80 % and 90 % in 82 patients. In 7 patients with a very high left-to-right shunt this value was 90 % or more. In 8 patients the oxygen saturation was lower than 80 %. In two girls with particularly low values (72 % and 68 %) the left-to-right shunt was estimated to be about 30 %. The difference in oxygen saturation between the pulmonary artery and superior vena cava in the entire series was, on the average, 19 %.

On *recatheterization* the oxygen saturation in the pulmonary artery was, on

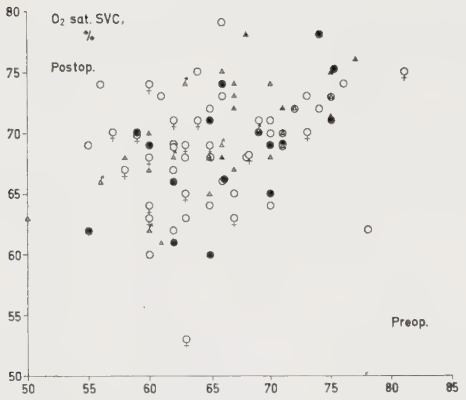


Fig. 6. Oxygen saturation in % in superior vena cava (SVC) on catheterization before operation (preop.) and at follow-up examination (postop.). Circles represent women, triangles men; open symbols = age group A, filled symbols = age group B. Circles with crosses, and triangles with arrows represent patients in age group C. Age group A = children; age group B = patients 15—29 years; age group C = patients 30 years or older.

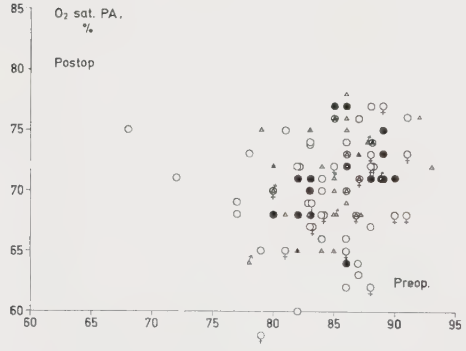


Fig. 7. Oxygen saturation in % in pulmonary artery (PA) on catheterization before and after operation. Symbols as in Fig. 6.

the average, 70 %. In 80 cases the values varied between 65 % and 75 %. The saturation difference between the pulmonary artery and superior vena cava was, on the average, 1 %. No signs of a residual left-to-right shunt were observed in any of the 107 patients. In 5 patients with a somewhat high oxygen saturation (77—78 %), however, the saturation difference between the pulmonary artery and superior vena cava was only 3 %. In 8 patients rather low values of between 58 % and 64 % were noted.

Left-to-right shunt, heart volume and systolic right ventricular pressure

Preoperatively the *left-to-right shunt* was, on the average, 61 % of the pulmonary blood flow; in two patients this value was unobtainable. No residual shunts were found at the follow-up examination. The distributions of patients in the different shunt and X-ray groups according to age groups is seen in Table 12. Eighteen patients (10 children and 8 adults) belonged to shunt group 1. The frequency of children (age group A) in shunt groups 2 and 3 was approximately equal, while the young adults (age group B) showed a greater frequency in shunt group 2, and the older adults (age group C) in shunt group 3.

A normal *heart volume* was seen in a total of 19 patients, 10 of whom were young adults in shunt group 2. Slight heart enlargement was observed in just over half, i.e. 58 of the patients, with a somewhat greater frequency in the children than in the adults. Moderate or pronounced heart enlargement was seen in 28 patients with predominance among the children, and older adults of shunt group 3.

The *systolic right ventricular pressure* was 30 mm Hg or more in 61 out of 102 patients. In only 6 patients was this 50 mm Hg or more. As seen in Table 13, normal systolic right ventricular pres-

Table 12. Distribution of patients in the different shunt and X-ray groups according to age groups.

Age group A

Heart size	Shunt group			Total	
	1	2	3	No.	%
Normal	4	1	—	5	10
Slight enlargement	4	17	12	33	66
Moderate enlargement	2	4	4	10	20
Pronounced enlargement	—	—	2	2	4
Total No.	10	22	18	50	
Total %	20	44	36		100

Age group B

Heart size	Shunt group			Total	
	1	2	3	No.	%
Normal	1	10	2	12	41
Slight enlargement	4	5	4	13	45
Moderate enlargement	—	1	2	3	11
Pronounced enlargement	—	1	—	1	3
Total No.	4	17	8	29	
Total %	14	58	28		100

Age group C

Heart size	Shunt group			Total	
	1	2	3	No.	%
Normal	1	1	—	2	7
Slight enlargement	2	3	7	12	47
Moderate enlargement	1	1	6	8	31
Pronounced enlargement	—	2	2	4	15
Total No.	4	7	15	26	
Total %	16	27	57		100

sures were more frequent in children than in adults, and in shunt groups 1 and 2 normal values for this pressure were just as frequent as raised values. In shunt group 3, on the other hand, raised systolic right ventricular pressures were most frequent, especially among the older adults. In many cases there was some relationship between size of left-to-right shunt and heart volume.

In the present series, however, no significant correlation was found between

Table 13. Distribution of patients in shunt and age groups according to RV systolic pressure.

Shunt group	RV systolic pressure, mm Hg	Age group A	B	C	Total
1	< 30	5	1	2	8
	⩾ 30	5	3	1	9
2	< 30	13	7	3	23
	⩾ 30	9	10	2	21
3	< 30	7	2	1	10
	⩾ 30	11	6	14	31

the size of the left-to-right shunt, expressed in % of the pulmonary blood flow, and the preoperative roentgenological heart volume, expressed in ml/m^2 body surface area, in any of the age groups. In the older adults, however, there was a significant correlation (*) between shunt size and systolic right ventricular pressure, but this was not found in the other two age groups.

At the follow-up examination no statistically certain correlation was found between shunt reduction and reduction of the relative heart volume or systolic right ventricular pressure, in the different age groups.

Intracardiac and intravascular pressures

The pressure results obtained on cardiac catheterization at rest before and after operation are summarized in Fig. 8.

Right atrium (RA). Preoperatively the mean pressure in the right atrium was, on the average, 3.7 mm Hg. In 24 patients, including 12 children, a mean pressure of over 5 mm Hg was found.

At *recatheterization* the mean pressure was 2.0 mm Hg. In 72 patients the pressure was lower than before the operation, in 17 patients it was unchanged and in 16 patients somewhat higher. 6 patients showed a mean pressure of more than 5 mm Hg. The mean pressure in RA, both preoperatively and at recatheterization, was somewhat higher in the children than in the older adults. This pressure was significantly (**) lower postoperatively than preoperatively.

Right ventricle (RV). Preoperatively the systolic pressure in the right ventricle was moderately raised, 32 mm Hg. 63 patients showed a pressure of 30 mm Hg or higher; this being somewhat more frequent in adults than in children. In 6 patients this pressure was 50 mm Hg or higher. Three of these had mild valvular pulmonary stenosis, which in two cases necessitated valvulotomy at the operation. In the third patient the systolic right ventricular pressure was still 50 mm Hg on recatheterization.

The end-diastolic pressure was, on the average, 2.8 mm Hg, i.e. normal, and the diastolic pressure gradient between the right atrium and right ventricle was 0.9 mm Hg.

On *recatheterization* the systolic right ventricular pressure was normal, 24 mm Hg. In 87 patients this pressure was now lower than preoperatively. In one patient it was unchanged and in 16 patients somewhat higher. In 16 patients (8 children, 5 young adults and 3 older adults) the pressure remained at 30 mm Hg or higher.

The end-diastolic pressure was essentially unchanged, 2.3 mm Hg.

The systolic right ventricular pressure was significantly lower (***) on re-

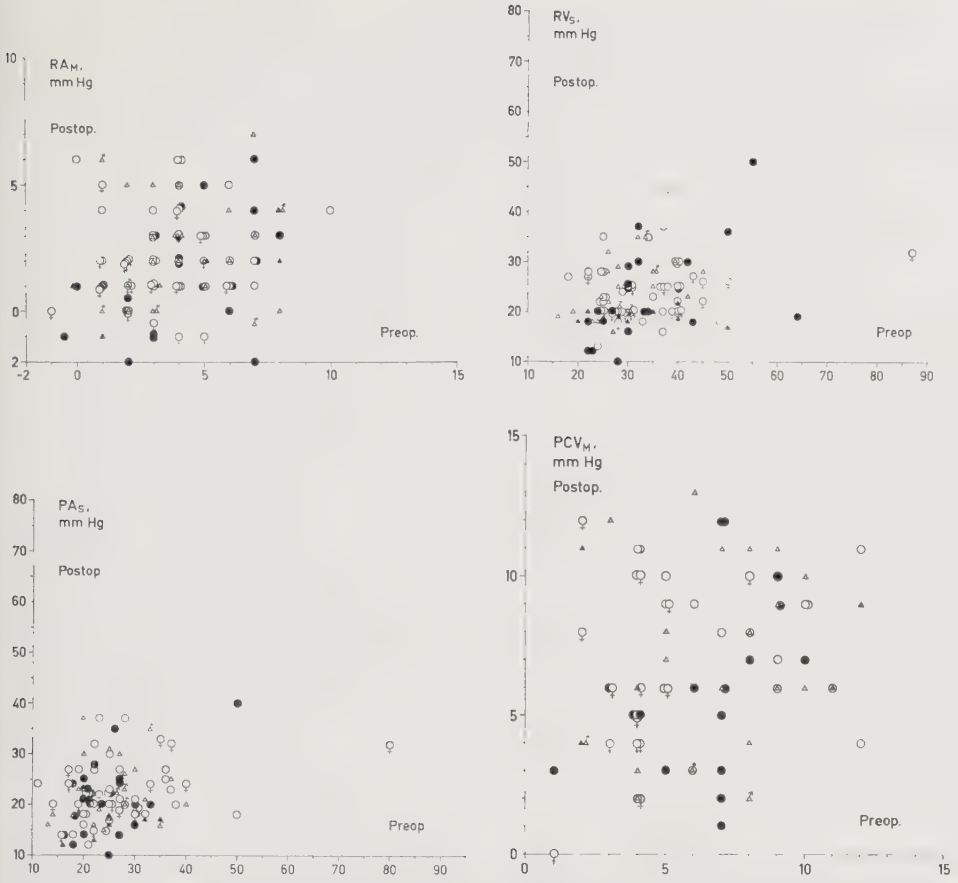


Fig. 8. Mean right atrial (RA) and pulmonary capillary venous (PCV) pressures, and systolic pressure in right ventricle (RV) and pulmonary artery (PA) in mm Hg before and after operation. Symbols as in Fig. 6.

catheterization than preoperatively. Neither before operation nor at recatheterization was there any definite sex or age difference with regard to the systolic or diastolic right ventricular pressures.

Pulmonary artery (PA). Preoperatively the systolic pressure in the pulmonary artery was, on the average, 26 mm Hg. In 27 patients this pressure was 30 mm Hg or higher, this value being somewhat more frequent in adults than in children. Only 3 patients had pulmonary hypertension, with systolic PA pressure of 50 mm Hg or more; in 2 of these patients this pressure was 50 mm Hg, and in 1 patient 80 mm Hg.

The diastolic and mean pressures were normal, with average values of 9 mm and 16 mm Hg, respectively.

The systolic *pressure gradient* between RV and PA was, on the average, 7 mm Hg. No definite relationship was found

between magnitude of shunt and pressure gradient. The pressure gradient is assessed from withdrawal curves, except in 8 patients with a technically negative gradient. In 64 out of 103 patients the systolic gradient between RV and PA was less than 10 mm Hg, in 25 patients this gradient lay between 10 and 20 mm Hg, and in only 6 patients was it above 20 mm Hg. In three patients with gradients of 31, 36, and 40 mm Hg, mild pulmonary valvular stenosis was present.

At *recatheterization* the systolic PA pressure was, on the average, 22 mm Hg. In 68 patients this pressure was now lower, in 3 patients it was unchanged and in 31 patients somewhat higher; in 14 of these latter patients a value of 30 mm Hg or more was noted. The systolic pressure in the pulmonary artery was, on the average, almost significantly (*) lower postoperatively than before operation.

The diastolic and mean pressures were 8 mm and 13 mm Hg, respectively.

The systolic *pressure gradient* between RV and PA was now, on the average, 2 mm Hg. In 77 patients the gradient was lower than before the operation, in 5 it was unchanged and in 16 patients somewhat higher. This gradient was significantly (**) lower on recatheterization than preoperatively.

Pulmonary capillary venous (PCV) pressure. Preoperatively the mean PCV pressure was normal, being on the average 6.4 mm Hg. The mean pressure was somewhat lower in older than in young patients.

On *recatheterization* this mean pressure was found, on the average, to be unchanged, 6.5 mm Hg. In 37 patients, however, the value was higher than preoperatively, while in 8 it was unchanged and in 29 lower. The mean pressure was also now, on the average, somewhat lower in older and young adults than in children.

There was no statistically significant change in the mean PCV pressure after the operation.

Left atrium (LA). Preoperatively the mean pressure in the left atrium was recorded in 76 patients and was found, on the average, to be 5.2 mm Hg, and somewhat higher in children and young adults than in the older persons. The difference in mean pressure between left and right atrium was, on the average, 1.5 mm Hg, and the corresponding value for PCV and left atrium 1.2 mm Hg. The difference in mean pressure between PCV and right atrium was 2.7 mm Hg before the operation and 4.5 mm Hg at the follow-up examination.

Left ventricle (LV). Preoperatively the left ventricular pressure was recorded in 47 patients; this was found to be, on the average, 98 mm Hg in children, 102 mm Hg in young adults and 117 mm Hg in the older adults. The end-diastolic pressures in these three age groups were 4.9, 4.9 and 5.8 mm Hg, respectively. There was no end-diastolic pressure difference between left atrium and left ventricle. The difference in end-diastolic pressure between the left and right ventricles was, on the average, 2.3 mm Hg.

Discussion

After successful surgical repair of an uncomplicated atrial septal defect of the secundum type, there is reason to ex-

pect completely normal conditions of pressure and oxygen saturation. If, on recatheterization, pathological changes are found, these may be attributable either to a residual left-to-right shunt, i.e. incomplete closure of the defect, or to incomplete regression of preoperative pathological conditions; this latter in turn may be due either to the fact that these conditions are not reversible, or may indicate a too short observation period after operation. In the present series no residual shunts were found, and the observation period between operation and follow-up examination was sufficiently long to allow a return to normal haemodynamic conditions.

It is always difficult to compare different clinical series. On evaluation of the present preoperative clinical and haemodynamic data certain differences were found from the results in atrial septal defect reported previously by Jonsson et al. (1957), Kjellberg et al. (1959), Davidsen (1960), Bedford (1961), Reindell et al. (1962), Storstein and Efskind (1963), and others; this can probably be explained by differences in the composition of the material with respect to age, types of defect and complicating abnormalities. With only few exceptions, the present series consisted by chance of patients with haemodynamically uncomplicated atrial septal defects of the secundum type, and can probably be regarded as representative of patients with this disease up to the age of 60 years.

When cyanosis occurs in atrial septal defect of the secundum type, the reason is usually suspected to be a right-to-left shunt caused by increase in resistance in the pulmonary circulation (Besterman 1961), in which case closure of the defect is contraindicated.

Woolf (1963) found, however, that raised pressure in the pulmonary artery in patients with ASD, could give rise to oedema in the alveolar-capillary membrane and reduced arterial oxygen saturation. This could probably explain the slight cyanosis noted preoperatively in one patient with moderately pronounced pulmonary hypertension of the hyperkinetic type and with reduced oxygen saturation in the pulmonary veins. After operation, performed with the aid of extracorporeal circulation, normalization of the pressures was observed, and normal saturation values, which indicates that a reversible change of the above type may have taken place. It is evident from the case described here that other causes for cyanosis in ASD sec can sometimes be demonstrated, which may mean that the patient can undergo operation with a good result.

Kjellberg et al. (1959) found that low posteriorly situated secundum defects, with the opening of the inferior vena cava directed towards the left atrium, could give rise to insignificant right-to-left shunts with reduced oxygen saturation in the left atrium, even though the pressure there was higher than in the right atrium. This was probably the explanation for the reduced oxygen saturation in the left atrium in two children with a normal pulmonary venous saturation, in whom maximal low posteriorly situated defects were found at operation.

It was of interest to note in the present series that the oxygen saturation in the superior vena cava lay at a normal level

at the follow-up examination, and was significantly higher (***) than preoperatively. The preoperative value, which lay at the lower normal limit, may thus have been an expression of increased peripheral utilization of the oxygen content of the blood, which may be associated with so called hypokinetic circulation.

Jonsson et al. (1957), in particular, have discussed the relationship between the size of the left-to-right shunt and the degree of roentgenological cardiac enlargement as an expression of the adaptation of the right heart to the shunt. Davidsen (1960) and Derra et al. (1965), and also Zaver and Nadas (1965) have reported this relationship. Kjellberg et al. (1959), Reindell et al. (1962) and Zaver and Nadas (1965) found, however, a normal heart volume in 8—12 % of their cases, this being somewhat more frequent in children and young adults. According to Bedford et al. (1957), increasing age is accompanied by a tendency to increasing heart volumes. Davidsen (1960) found that pronounced cardiac enlargement, above that which can be explained by the shunt, was prognostically unfavourable, and was usually an expression of myocardial and/or valvular disorders.

A normal heart volume preoperatively need not, however, exclude the existence of a relationship between shunt magnitude and heart size. The shunt volume involves the right atrium and ventricle, where a large shunt volume should cause more pronounced enlargement than a small volume, under conditions similar in other respects (myocardial function, flow resistance). Conceivably, therefore, the total relative heart volume could be normal in such cases where the left ventricle, perhaps because of lack of physical training, is relatively smaller than normally (Jonsson 1966). After the operation a volume reduction may then be an expression of flow reduction in the right heart.

At the follow-up examination, however, no statistically certain correlation was found, in the present series, between shunt reduction and reduction of the relative heart volume or systolic right ventricular pressure, in the different age groups.

Some overrepresentation of large left-to-right shunts in older patients can be explained by the fact that these patients had had symptoms which led to cardiological investigation.

The postoperative pressure reaction at rest in the pulmonary circulation was in accordance with previous findings, and involved a reduction from slightly raised or high normal pressure levels to normal values (Kirklin et al. 1956). This can be considered to agree with the haemodynamic mechanism in patients with uncomplicated secundum defects, and can be explained by the hyperkinetic effect of the left-to-right shunt which results in a pressure increase to high normal values but not usually to values that are pathologically raised.

The pressure difference between the atria in uncomplicated atrial septal defect has been described by Kjellberg et al. (1959), among others, and in the present series this was, on the average, 1.5 mm Hg. The mean pressure in both the right and the left atrium, and also the mean PCV pressure, were somewhat

higher in the young than in the older adults, which is in agreement with investigations in normal persons according to Granath et al. (1964). It is always difficult in clinical series to assess the significance of small pressure differences, especially where mean pressures and filling pressures are concerned. The mean PCV pressure was, however, the only pressure which showed no significant change, this remaining at a normal level at the follow-up examination. Preoperatively the mean PCV pressure was, on the average, 1 mm higher than the mean pressure in the left atrium, and therefore this pressure difference was probably of approximately equal magnitude postoperatively also. In that case the postoperative pressure difference between the atria will be normal, i.e. approximately 3 mm Hg, which then means normal filling pressures in the respective ventricles. This also means that preoperatively the filling pressure was raised for the right ventricle and, in many cases, was lowered for the left, compared with normal values. The normal pressure difference between the left and right atrium depends on the difference in resistance between the left and right ventricular circulation, the left ventricle requiring a higher filling pressure than the right ventricle. Also, according to Berglund (1955), at the same filling pressure the stroke volume of the right ventricle exceeds that of the left ventricle. The normal pressure difference between the atria is influenced by the septal defect, and when this defect is sufficiently large a pressure equilibration takes place which is clearly unphysiological in consideration of the normal filling pressure and functional mechanism of both the right and the left ventricle. These pressure relationships form prerequisite conditions for the occurrence of a left-to-right shunt, but they may also mean some reduction of the filling of the left ventricle and the systemic flow.

The postoperative pressure reduction was most pronounced in the right ventricle (***), right atrium (**) and in the pulmonary artery (*), while the mean PCV pressure showed no significant change, and therefore the pressure gradient across the pulmonary capillary bed remained essentially unaltered and independent of the pulmonary blood flow. However, among the older patients with large left-to-right shunts preoperatively, there was a tendency towards higher mean PCV pressures postoperatively. This was probably an expression of increased filling pressure of the left ventricle.

The frequency of pulmonary hypertension reported in ASD sec varies considerably, due mainly to differences in definition and in the composition of the series of patients described. Besterman (1961) found a frequency of 16 % with systolic PA pressure equal to or higher than 50 mm Hg, among a series of 225 ASD sec. Derra et al. (1965) found from literature reports a frequency varying between 13 and 25 %. Only 3 patients (2.6 %) in the present series had pulmonary hypertension, which thus seems a remarkably low frequency. The frequency of pulmonary hypertension increases with advancing age, and in addition, recurrent upper respiratory infections probably play an important role (Besterman

1961). In the present series only 4 patients were over 50 years of age, and there was no tendency to recurrent upper respiratory infections which may explain, at least partly, the low incidence of pulmonary hypertension.

No correlation was found in the present series between the size of the left-to-right shunt and the pressure gradient between the right ventricle and pulmonary artery. This gradient was probably caused by the preoperatively increased flow, due to the effect of "pressure loss of velocity" (Jonsson 1957).

Summary

The oxygen saturation and pressure conditions at rest before and, on the average, 17 months after surgical repair of ASD sec in 107 patients are reported.

The left-to-right shunt was preoperatively, on the average, 61 % of the pulmonary blood flow. No significant correlation was found between the size of the left-to-right shunt, expressed in % of the pulmonary blood flow, and the preoperative roentgenological heart volume, expressed in ml/m^2 body surface area, in any of the age groups. No residual shunts were found on recatheterization. The oxygen saturation in the superior vena cava was normal, and significantly higher (***) postoperatively, indicating preoperatively increased peripheral utilization of the oxygen content. At the follow-up examination no statistically certain correlation was found between shunt reduction and reduction of the relative heart volume.

Preoperatively, the pressures in the pulmonary circulation were high but within the normal range; only three patients had pulmonary hypertension. On recatheterization the pressures were significantly lower in the right atrium (**), right ventricle (***) and the pulmonary artery (*), which shows that preoperatively the left-to-right shunt gave rise to a pressure increase to high normal but not pathological values. Only in the older adults, was there a significant correlation (*) between shunt size and systolic right ventricular pressure. At the follow-up examination no statistically certain correlation was found between shunt reduction and reduction of systolic right ventricular pressure, in the different age groups.

The mean PCV pressure was normal and showed no significant change postoperatively, and therefore the pressure gradient across the pulmonary capillary bed was essentially independent of the pulmonary blood flow. On comparing the filling pressures of the ventricles pre- and postoperatively, it was found that before the operation, because of the defect, this pressure was increased for the right ventricle and, in many cases, was decreased for the left, compared with normal values. The pressure relationships and the functional mechanisms of both the right and the left ventricle were unphysiological and were prerequisite conditions for the occurrence of a left-to-right shunt, and possibly also for reduced systemic flow. Postoperatively, a normal pressure difference between the atria, and prerequisite conditions for normal filling pressure, were noted.

CHAPTER VIII

Haemodynamic findings at rest and during exercise in 51 patients at follow-up examination

In 51 patients pressure and flow determinations were made both at rest and during exercise, on recatheterization.

These patients (5 girls and 6 boys in age group A, 18 women and 5 men in age group B, and 15 women and 2 men in age group C) showed no essential difference clinically or at rest haemodynamically from the other patients of the series either preoperatively or at the follow-up examination about 18 months after the operation. The results for this group have been compared with values for young normal persons given by Holmgren, Jonsson and Sjöstrand (1960), and Bevegård, Holmgren and Jonsson (1960) and for older normal persons by Granath, Jonsson and Strandell (1964) and Malmborg (1964).

Of the remaining 56 patients, of whom 39 were children, exercise tests during recatheterization were either not carried out, for various reasons, or were unsatisfactory.

The results obtained on cardiac catheterization at rest and during exercise are summarized in Tables 14 and 15 and Figs. 9—14. In view of the differences in haemodynamic conditions in children, women and men, the results for the different age groups are reported separately.

Circulatory function

Heart rate. At rest the heart rate in the children was, on the average, 81 beats per minute, in the women in age groups B and C 72 beats per minute and in the men in age groups B and C 63 beats per minute. One girl in age group A with a heart rate of 48 had an A-V block II, the block being constantly 2:1. One woman with atrial fibrillation had a relatively regular, slow ventricular frequency (73/min). In all other cases there was sinus rhythm with a normal frequency.

Oxygen uptake. At *rest* the oxygen uptake in the children, women and men was, on the average, 2.8 %, 18.6 % and 12.4 % higher, respectively, than the basal oxygen uptake. In the women and men the basal metabolic rate lay within the normal limits; this was not investigated in the children. In no case were any clinical signs of thyroid dysfunction seen.

On cardiac catheterization during *exercise* the oxygen uptake increased to a normal extent with increasing work loads. The mean value for the degree of mechanical efficiency was 20 % in the children and women and 22 % in the men, at a work load which increased the heart rate to an average of 134 beats/min, 134 beats/min and 123 beats/min, respectively, in these three groups.

TABLE 14. Observations during heart catheterization *at rest* in 51 pat. at the follow-up examination.

Age groups and sex	Characteristic	No.	Heart rate, beats/min	Oxygen saturation per cent		AVD ml/l	Oxygen uptake ml/min STPD	Cardiac output 1/min	Cardiac index 1/min per m² BSA	Stroke volume ml	Stroke volume index ml/m² BSA
				BA	PA						
A Girls	mean	5	76	97.9	72.6	41.5	183	4.4	3.6	61	47
Boys	»	6	85	96.6	75.1	37.2	167	4.5	4.1	55	51
Total	»	11	81	97.3	74.0	39.2	174	4.5	3.8	57	49
	min.		48	94.0	69.1	30.0	149	3.8	2.8	42	37
	max.		107	99.2	77.0	44.0	203	5.5	5.7	98	62
	SD		14.8	1.8	5.6	4.4	12.3	0.7	0.9	16.4	9.3
	SE		4.4	0.5	1.7	1.3	3.7	0.2	0.3	4.9	2.8
B Women	mean	18	70	98.4	72.2	39.4	221	5.7	3.5	84	51
Men	»	5	63	99.4	74.0	47.3	275	5.9	3.1	91	47
C Women	»	15	76	98.6	68.1	45.3	218	4.9	3.0	66	41
Men	»	2	62	97.9	70.5	44.5	266	6.0	3.0	96	48
B+C Women	mean	33	72	98.5	69.1	41.2	219	5.5	3.3	76	45
	min.		48	96.7	58.2	30.5	158	3.5	2.3	48	35
	max.		102	100.0	81.7	55.8	281	8.3	4.7	129	62
	SD		12.3	1.3	4.0	6.7	27.2	1.2	0.8	19.2	4.4
	SE		2.1	0.2	0.7	1.1	4.7	0.2	0.1	3.3	0.8
B+C Men	mean	7	63	98.9	73.0	46.5	273	5.9	3.1	92	48
	min.		52	95.8	70.4	36.1	253	5.1	2.7	74	37
	max.		73	100.0	81.9	53.9	295	7.0	4.1	96	60
	SD		8.5	1.7	4.2	5.2	14.3	0.6	0.6	14.1	9.5
	SE		3.2	0.6	1.6	1.9	5.4	0.2	0.2	5.3	3.6

RA = right atrium
RV = right ventricle
PA = pulmonary artery
BA = brachial artery
PCV = pulmonary capillary venous pressure
S = systolic pressure
D = diastolic pressure
M = mean pressure
AVD = arteriovenous oxygen difference

Arterial oxygen saturation. The arterial oxygen saturation lay within the normal limits both at rest and during exercise. At rest the mean value was, on the average, 98.1, and during exercise somewhat lower, 97.3.

Oxygen saturation of mixed venous blood (Fig. 9). At *rest* the mean oxygen saturation of mixed venous blood drawn from the pulmonary artery was, on the average, 71.7.

Pressures, mm Hg										Pulm. vasc. resist. (R_P)	Pulm. vasc. resist. index (R_{i_P})	Systemic vasc. resist. (R_S)	Systemic vasc. resist. index (R_{i_S})
RA	RV		PA			PCV	BA						
M	S	D	S	D	M	M	S	D	M				
2.4	27	2.6	23	7	12	5.2	122	68	93	1.4	2.0	20.2	26.1
3.5	29	4.5	31	9	14	8.6	122	63	87	1.8	1.7	19.2	20.4
3.0	28	3.6	25	8	13	7.1	122	65	90	1.6	1.8	19.6	23.4
0	18	1.0	15	5	9	2.0	100	50	70	0.8	0.7	14.5	17.5
6.0	35	6.0	30	14	17	13.0	140	80	105	3.0	2.9	24.3	31.8
2.1	6.3	1.9	8.7	3.2	4.9	4.7	11.6	13.1	11.7	0.7	0.5	2.9	4.8
0.7	1.9	0.6	2.6	0.9	1.5	1.5	3.5	3.9	3.5	0.2	0.2	0.9	1.5
1.7	24	1.8	22	7	12	6.5	134	73	94	1.0	1.4	15.7	21.7
1.2	20	2.4	17	6	10	5.2	136	70	93	0.8	1.5	16.0	31.7
1.0	25	2.8	23	9	13	6.2	143	73	99	1.6	2.5	20.9	33.0
0.5	20	2.2	23	8	13	3.5	140	85	105	1.4	1.6	17.5	23.8
1.4	25	2.3	23	8	13	6.3	138	73	98	1.3	1.9	18.1	26.8
—2.0	10	—4.0	10	2	7	0	120	60	70	0.2	0.3	12.6	23.1
6.0	50	8.0	40	11	20	13.0	200	100	140	3.4	5.1	33.4	52.3
2.0	8.2	2.3	6.5	3.4	10.6	2.9	15.3	10.8	14.0	0.9	1.2	4.9	8.3
0.4	1.4	0.4	1.1	0.6	1.8	0.5	2.7	1.8	2.4	0.1	0.2	0.8	1.4
1.0	20	2.3	19	7	11	4.9	137	74	96	1.0	1.5	16.9	29.2
—1.0	18	—1.0	12	2	8	3.0	120	60	80	0.4	0.5	12.7	22.2
4.0	22	4.0	22	10	15	7.0	160	80	115	1.9	4.1	22.7	49.0
2.4	4.7	1.3	5.9	2.7	3.0	3.0	12.5	9.5	5.0	0.6	1.1	2.4	10.0
0.9	1.8	0.4	2.2	1.0	1.1	1.1	4.7	3.6	1.9	0.2	0.4	0.9	3.8

Age group A: Children up to 15 years
B: Women and men 15—29 years
C: Women and men 30 years or more

$$R_P = \frac{\bar{P}_{PA} - \bar{P}_{PCV}}{\dot{Q}} \qquad R_S = \frac{\bar{P}_{BA} - \bar{P}_{RA}}{\dot{Q}}$$

$$R_{i_P} = \frac{\bar{P}_{PA} - \bar{P}_{PCV}}{\dot{Q}} \cdot BSA \qquad R_{i_S} = \frac{\bar{P}_{BA} - \bar{P}_{RA}}{\dot{Q}} \cdot BSA$$

In most cases during *exercise* the saturation decreased to a normal extent with increasing work load and heart rate, but to values which lay at the lower normal limit. Three patients in age group B showed a rather high oxygen saturation at rest, but this decreased to a normal extent during exercise. A girl in age group A with an A-V block II (2: 1) showed a normal reduction of the

TABLE 15. Observations on heart catheterization during work in 51 pat. at the follow-up examination.
Abbreviations as in Table 14.

Age groups and sex	Characteristic	No.	Work load kpm/min	Heart rate, beats/min	Oxygen saturation per cent		AVD ml/l	Oxygen uptake ml/min STPD	Cardiac output l/min	Cardiac index l/min per m² BSA	Stroke volume ml	Stroke volume index ml/m² BSA
					BA	PA						
A Girls	mean	5	250	132	96.8	41.9	92.0	784	8.4	6.6	74	53
Boys	»	6	250	135	96.5	42.5	90.0	691	7.7	7.0	57	53
Total	»	11	250	134	96.7	43.7	91.0	734	8.0	6.8	65	53
	min.			66	95.6	28.6	71.8	560	6.7	5.1	41	38
	max.			164	99.3	53.9	117.3	1 045	10.6	8.3	62	93
	SD			28.9	1.3	7.4	13.0	175.7	1.4	1.3	32.3	1.8
	SE			8.5	0.4	2.2	3.9	52.9	0.4	0.4	9.7	0.5
B Women	mean	18	400	142	97.5	44.6	94.6	1 163	12.2	7.3	87	53
Men	»	5	600	123	98.0	48.2	108.9	1 519	13.9	7.2	112	55
C Women	mean	15	300	127	97.7	43.5	96.7	914	9.4	5.7	76	46
Men	»	2	500	122	96.2	43.6	112.2	1 370	12.0	5.2	98	48
B+C Women	mean	33	350	134	97.6	44.1	95.5	1 080	10.9	6.7	82	50
	min.			76	94.3	29.3	78.4	437	5.1	4.3	42	27
	max.			171	100.0	66.4	120.1	1 782	17.0	9.8	133	85
	SD			25.3	4.9	5.9	14.6	282.1	2.3	1.7	19.6	3.8
	SE			4.4	0.8	1.0	2.5	49.0	0.4	0.3	3.4	0.7
B+C Men	mean	7	550	123	97.5	46.9	109.7	1 476	13.3	6.9	108	53
	min.			100	95.2	41.2	93.7	996	10.1	4.7	84	40
	max.			150	100.0	55.6	123.0	2 211	20.3	10.7	135	70
	SD			18.7	3.7	2.2	7.9	412.6	3.0	1.8	16.0	8.3
	SE			7.1	1.4	0.8	3.0	155.7	1.1	0.7	6.0	3.1

oxygen saturation on increase of the heart rate from 48 beats/min at rest to 66 during exercise. One woman in age group C with normal resting values showed a negligible saturation reduction in relation to the heart rate. The lowest value was noted in a boy in age group A (28.6 %). During exercise, no difference in the oxygen saturation in mixed venous blood was found between the different age groups.

Arteriovenous oxygen difference (Figs. 10 and 11). At *rest* the mean arteriovenous oxygen difference (AVD ml/l) was, on the average, 39.2 ml/l in children, 41.2 ml/l in women and 46.5 ml/l in men. 15 patients showed values higher than 45 ml/l.

During *exercise* the values increased with increasing work loads, and varied between 71.8 and 123.0 ml/l. The arteriovenous oxygen difference values have been plotted against oxygen uptake in Fig. 10, and against heart rate in Fig. 11,

Pressures, mm Hg										Pulm vasc. resist. (R_P)	Pulm vasc. resist. index (R_{I_P})	Systemic vasc. resist. index (R_S)	Systemic vasc. resist. index (R_{I_S})
RA	RV		PA			PCV	BA						
M	S	D	S	D	M	M	S	D	M				
2.7	36	2.6	34	13	22	8.8	160	81	108	1.7	2.3	13.8	17.2
2.0	36	4.5	33	16	21	10.3	148	82	102	1.5	1.6	13.5	14.3
2.4	36	3.7	34	15	22	9.6	152	81	104	1.6	1.8	13.6	15.7
1	30	1	25	5	17	9	130	60	90	0.1	0.2	11.3	10.7
11	47	7	47	20	30	17	175	90	120	3.5	4.3	15.1	20.0
1.4	5.1	1.8	7.1	6.6	5.3	3.1	19.5	10.5	11.8	0.9	1.1	1.9	3.2
0.4	1.5	0.5	2.1	2.0	1.6	0.9	5.9	3.2	3.6	0.3	0.3	0.6	1.0
1.6	49	4.2	39	16	23	10.3	174	86	117	1.1	1.7	9.9	16.6
—1.8	34	1.8	31	10	16	7.6	176	84	110	0.6	1.3	7.9	16.7
0.8	45	3.5	43	18	26	10.2	172	99	131	1.8	3.0	14.6	23.7
2.0	56	2.0	47	23	25	11.5	202	97	127	1.1	2.3	10.7	22.2
1.2	47	3.8	40	17	24	10.3	182	91	122	1.4	2.2	11.7	19.6
—4	27	—6	27	7	14	1	110	55	75	0.2	0.4	6.2	9.2
10	95	15	60	32	45	18	240	140	180	4.2	6.7	27.6	42.0
2.6	12.0	1.9	9.8	5.9	8.4	5.4	29.4	5.1	21.7	0.8	1.3	3.5	3.1
0.4	2.1	0.3	1.7	1.0	1.5	0.9	5.1	0.9	3.8	0.1	0.2	0.6	0.5
—0.7	40	1.9	35	14	19	8.7	182	88	115	0.9	1.4	8.7	18.3
—4	30	—5	25	5	15	6	140	70	85	0.3	0.5	4.2	7.9
12	62	4	55	32	25	12	240	105	150	1.3	2.7	12.4	26.5
4.2	4.8	3.2	3.3	4.1	3.4	2.5	10.0	18.2	23.2	0.3	0.5	2.4	5.5
1.6	1.8	1.1	1.2	1.5	1.3	0.9	3.8	6.9	8.7	0.1	0.2	0.9	2.1

both at rest and during exercise. In relation to the oxygen uptake most patients showed, during exercise, a somewhat high arteriovenous difference which was not quite parallel with the normal curvilinear regression line. In relation to the heart rate, most patients showed a normal increase of the arteriovenous oxygen difference during exercise.

Cardiac output (Fig. 12 A—C). At *rest,* the mean cardiac output in age group A was 4.5 l/min, with no difference between boys and girls. In the women of age group B this value was 5.7 l/min, and in those of age group C, 4.9 l/min. The corresponding values for cardiac index were 3.8, 3.5 and 3.0 l/min per m^2 body surface area, respectively. In the men in age group B the mean cardiac output was 5.9 l/min, and in those of age group C, 6.0 l/min, with corresponding cardiac index values of 3.1 and 3.0 l/min per m^2 body surface area, respectively. The cardiac index

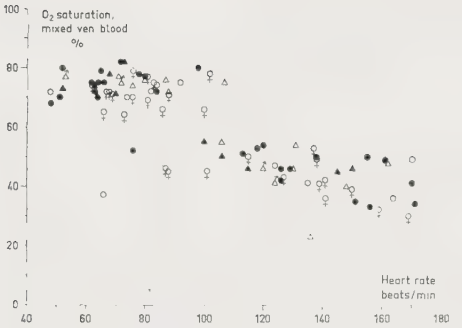


Fig. 9. Oxygen saturation of mixed venous blood (in pulmonary artery), in per cent, in relation to heart rate (beats/min) at rest and during exercise. Circles represent women, triangles men; open symbols = children, filled symbols = patients in age group B. Circles with crosses, and triangles with arrows represent patients in age group C.

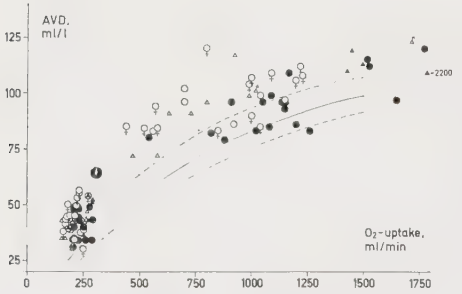


Fig. 10. Arteriovenous oxygen difference (AVD), ml/l, in relation to oxygen uptake, ml/min, at rest and during exercise. Central line indicates regression between these parameters, interrupted lines ± standard error of estimate for normal persons according to Holmgren et al. and Bevegård et al. in Irnell (1964). Symbols as in Fig. 9.

values at rest lay within the normal limits (See Cullhed, 1964, for further references).

During *exercise,* the cardiac output in age group A increased to an average of 8.0 l/min. In the women of age groups B and C the values increased to 12.2 and

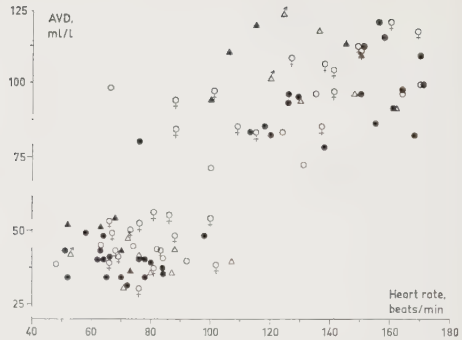


Fig. 11. Arteriovenous oxygen difference (AVD), ml/l, in relation to heart rate (beats/min), at rest and during exercise. Symbols as in Fig. 9.

9.4 l/min, and in the men 13.9 and 12.0 l/min, respectively.

Stroke volume (Fig. 12 D). At *rest,* the mean stroke volume in age group A was 57 ml, with no difference between boys and girls. In the women of age groups B and C the stroke volumes were 84 and 66 ml, and in the men 91 and 96 ml, respectively. The stroke volumes in the patients of age groups B and C were somewhat lower than the values which have been given for normal persons.

During *exercise,* the stroke volume in age group A increased by an average of 8 ml. In age groups B and C the increases for the women were 3 ml and 10 ml, and for the men 21 ml and 2 ml, respectively.

Intracardiac and intravascular pressures

The results obtained on pressure measurement at rest and during exercise are summarized in Fig. 13.

Right atrium. At *rest* the mean pressure in the right atrium was, on the average, 3.0 mm Hg in the children, 1.4

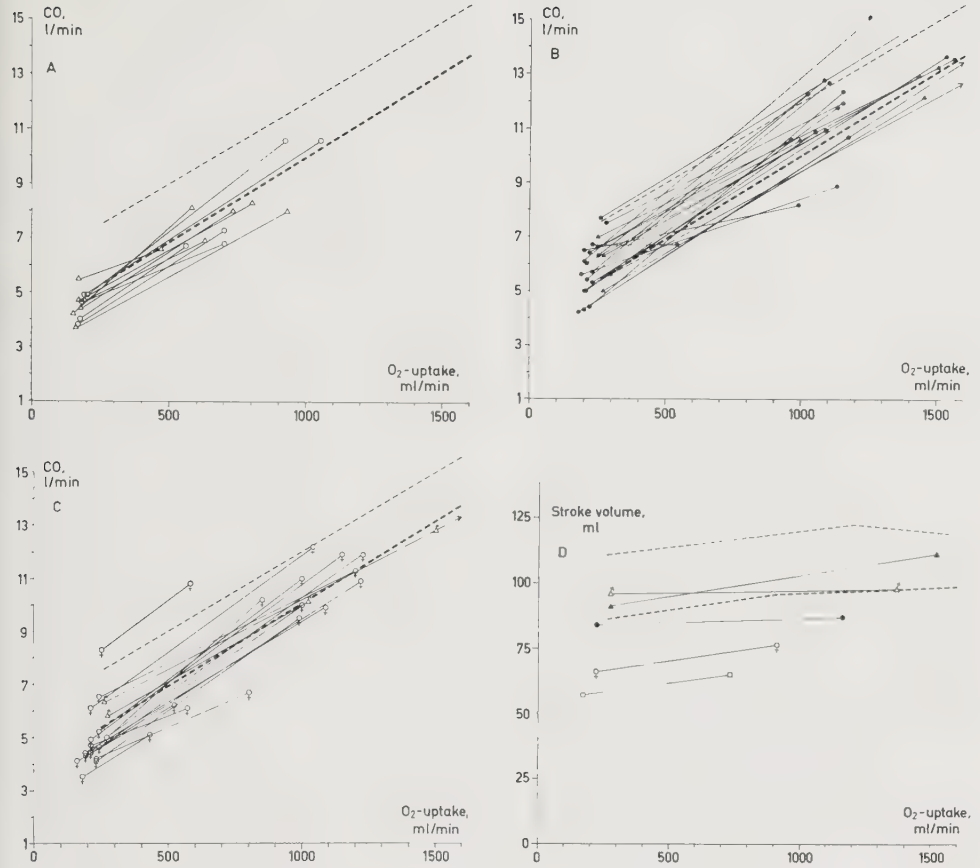


Fig. 12. Oxygen uptake (ml/min) in relation to cardiac output (1/min), at rest and during exercise. Regression lines for cardiac output on oxygen uptake in old (heavy broken line) and young (thin broken line) normal persons according to Granath et al. (1964). Symbols as in Fig. 9.

Fig. 12 A shows the conditions for 11 children in age group A,

Fig. 12 B for 18 females and 5 males in age group B, and

Fig. 12 C for 15 females and 2 males in age group C.

In Fig. 12 B and C (see arrows) there was no room for three symbols, representing cardiac output values of 14.8, 15.5 and 14.0 l/min, and oxygen uptake values of 1790, 2140 and 1720 ml/min.

Fig. 12 D: Mean stroke volume (ml) in relation to oxygen uptake (ml/min), at rest and during exercise. Mean stroke volumes in old (heavy broken line) and young (thin broken line) normal persons according to Granath et al. (1964). Squares represent children. Other symbols as in Fig. 9.

mm Hg in the women and 1.0 mm Hg in the men.

During *exercise* this value decreased to 2.4 mm Hg and –0.7 mm Hg, respectively.

These values, both at rest and during exercise, lay within the normal limits of variation.

Right ventricle. At *rest,* the systolic pressure in the right ventricle was, on the

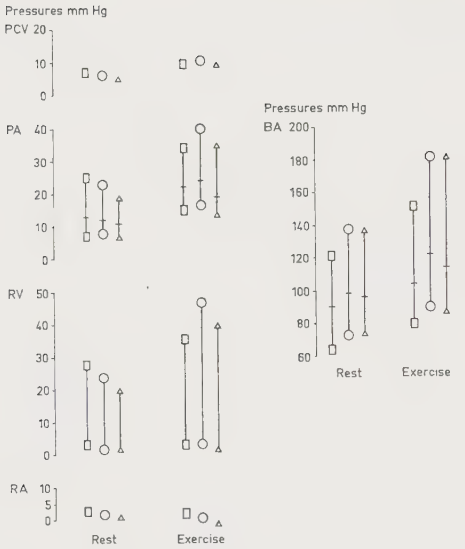


Fig. 13. Mean values for pressures, in mm Hg, at rest and during exercise in 11 children (squares), 33 females (circles) and 7 males (triangles). Notation as in Table 14.

average, 28 mm Hg in the children, 24 mm Hg in the women and 20 mm Hg in the men. The corresponding figures for end-diastolic pressure were 3.6, 2.3 and 2.3 mm Hg, respectively.

During *exercise* these values increased with increasing work loads, to average values of 36 mm Hg in the children, 47 mm Hg in the women and 40 mm Hg in the men. The end-diastolic pressure during exercise was 3.7 mm Hg, 3.8 mm Hg and 1.9 mm Hg in the three respective groups.

Pulmonary artery. At *rest,* the systolic pressure in the pulmonary artery was 25 mm Hg in the children, 23 mm Hg in the women and 19 mm Hg in the men. At rest the systolic pressure gradient between the right ventricle and pulmonary artery was 3 mm Hg in the children and 1 mm Hg in the women and men.

During *exercise* the systolic pressure in the pulmonary artery increased in the same way as the systolic pressure in the right ventricle, and in the children this value was now 34 mm Hg, in the women 40 mm Hg and in the men 35 mm Hg. During exercise, the systolic pressure gradient in the children was 2 mm Hg, in the women 7 mm Hg and in the men 4 mm Hg.

The mean pressure in the pulmonary artery at rest was 13 mm Hg in the children, 13 mm Hg in the women and 11 mm Hg in the men. During exercise these values increased to 22, 24, and 19 mm Hg, respectively.

Pulmonary capillary venous pressure. At *rest,* the mean PCV pressure was 7.1 mm Hg in the children, 6.3 mm Hg in the women and 4.9 mm Hg in the men. The highest mean PCV pressure was 13 mm Hg.

During *exercise* these values increased to 9.6, 10.3 and 8.7 mm Hg, respectively. The highest value during exercise was 18 mm Hg.

Brachial artery. At *rest,* the systolic pressure was, on the average, 122 mm Hg in the children, 138 mm Hg in the women and 137 mm Hg in the men. The corresponding mean pressure values were 90, 98 and 96 mm Hg. Two women in age group C had moderate arterial hypertension with systolic pressures of 185—200 and diastolic pressures of 100 mm Hg.

During *exercise* the systolic pressure increased to 152 mm Hg in the children and 182 mm Hg in the women and men. The mean pressure values for these three groups were 104, 122 and 115 mm Hg, respectively. The highest values for systol-

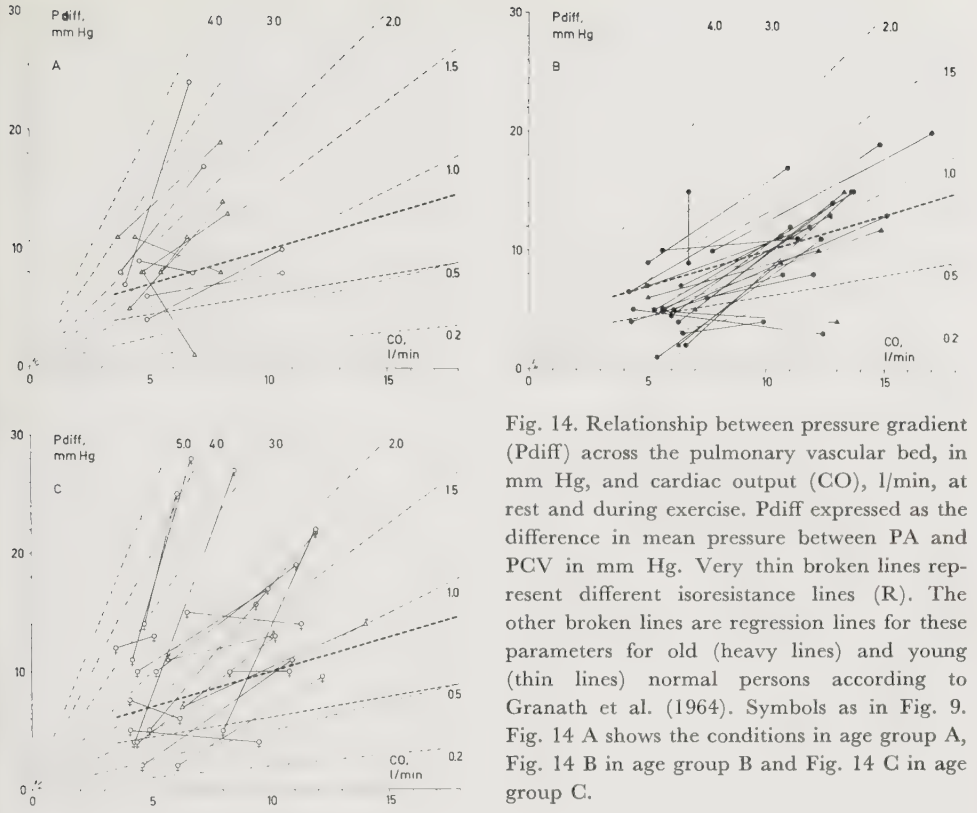


Fig. 14. Relationship between pressure gradient (Pdiff) across the pulmonary vascular bed, in mm Hg, and cardiac output (CO), l/min, at rest and during exercise. Pdiff expressed as the difference in mean pressure between PA and PCV in mm Hg. Very thin broken lines represent different isoresistance lines (R). The other broken lines are regression lines for these parameters for old (heavy lines) and young (thin lines) normal persons according to Granath et al. (1964). Symbols as in Fig. 9. Fig. 14 A shows the conditions in age group A, Fig. 14 B in age group B and Fig. 14 C in age group C.

ic pressure during exercise, i.e. 240 and 270 mm Hg, were recorded in the two women who had shown raised pressure at rest.

Pulmonary vascular resistance (R_P, Fig. 14). At *rest* the pulmonary vascular resistance, expressed as mm Hg per l/min, was on the average, 1.6 in the children, 1.3 in the women and 1.0 in the men. The corresponding values for pulmonary vascular resistance index (R_{iP}). expressed as mm Hg per l/min $\times$ m^2 body surface area were 1.8, 1.9 and 1.5, respectively. These mean values were within the normal limits, but in the older women, in particular, a tendency to an increased pulmonary vascular resistance was seen.

During *exercise* the pulmonary vascular resistance decreased in approximately one half of the patients, but large individual variations were noted in the different age groups. Compared with the resistance at rest, no statistically significant change was noted during exercise.

Systemic vascular resistance (R_S). At *rest*, the systemic vascular resistance, expressed as mm Hg per l/min, was, on the average, 19.6 in children, 18.1 in women and 16.9 in men. The corresponding values for systemic vascular resistance index (R_{iS}), expressed as mm

Hg per l/min × m^2 body surface area, were 23.4, 26.8 and 29.2 respectively. These values lay within the normal limits except in the two patients with arterial hypertension.

During *exercise* the systemic vascular resistance decreased to an essentially normal extent.

Discussion

Up to the present time no reports appear to have been made which have illustrated the haemodynamic conditions both at rest and during work in patients with surgically repaired secundum defects. It seemed of interest, therefore, to study these conditions in a series of patients 18 months, on the average, after open repair of a haemodynamically uncomplicated secundum defect, where both the operation and the postoperative course were free of complications.

From a clinical aspect it is important to know, not only that the defect is closed but, above all, the general cardiac condition of the patient after the operation. It was therefore of especial interest to determine whether, and if so in what way, this series of patients with surgically repaired secundum defects differed haemodynamically from normal subjects.

Circulatory efficiency, i.e. cardiac output in relation to oxygen uptake and heart rate. During exercise, the majority of patients showed a somewhat higher arteriovenous oxygen difference than the normal in relation to the oxygen uptake, while, on the other hand, the arteriovenous oxygen difference in relation to the heart rate was essentially normal. Since the oxygen uptake and mechanical efficiency were normal, these patients showed, on the average, a lower cardiac output during exercise, but this increased, however, in a normal way with increasing work loads.

The cardiac output values at rest in the different age groups lay at the lower normal limit, while the cardiac index values were within the normal range of variations. The stroke volume was, on the average, lower than the values reported for young healthy persons, and was in closer agreement with the conditions seen in older, healthy men. During exercise, however, the stroke volume increased to a normal extent, following in the main the values given for normal persons.

Patients with a low cardiac output in relation to the oxygen uptake, and a high arteriovenous oxygen difference in relation to the heart rate, are designated as having a hypokinetic circulation, in contrast to those with a hyperkinetic circulation as pointed out e.g. by Holmgren et al. (1957). A tendency to hypokinetic circulation has been demonstrated in elderly normal men, by Strandell (1964), and in asthmatic patients by Irnell (1964). In both of these series an increase in the arteriovenous oxygen difference in relation to the oxygen uptake, and also a reduction of the maximal heart rate, were observed with advancing age, and this resulted in a tendency to an increase in the arteriovenous difference in relation to the heart rate.

The results of the haemodynamic studies in patients with surgically repaired secundum defects were in close agree-

ment with the conditions in hypokinetic circulation. On the other hand, in most cases the arteriovenous difference was normal in relation to the heart rate, and therefore from this point of view these patients could be said to have a normokinetic circulation.

On making comparisons with the normal values given, consideration should be taken, not only of age, but also of the fact that these normal values are based on investigations in men, while the present series is comprised predominantly of women, in whom the circulatory efficiency may be different.

The pressures at rest in the pulmonary circulation and PCV were normal, and on the average somewhat higher in the children than in the women and men. The pressure in the brachial artery was normal in the children and adults.

During exercise the pressures increased to an essentially normal extent. The pressure increases were somewhat more pronounced in the older patients compared with the children; the pressure difference between the young and older patients during exercise was in agreement with the findings of Granath et al. (1964), and may be explained by age-dependent structural changes with increasing vascular rigidity. In these patients, who before the operation, because of the left-to-right shunt, showed a greatly augmented pulmonary blood flow, the elasticity function in the main branch of the pulmonary artery may have been reduced. Such vascular changes are probably more pronounced in older than in young patients, and may then produce a tendency to reduced pressure tolerance, especially during exercise. The mean PCV pressure increased to a normal extent during work, this increase being somewhat higher in older than in young patients. This was in accordance with previous findings, and was probably due to the fact that the filling pressure in the left ventricle increases to some extent during exercise with advancing age (Granath et al. 1964).

The mean values for pulmonary vascular resistance were within the normal limits both at rest and during exercise, but there was a tendency to high normal or raised values among the older patients. This is explained by the fact that in these patients the pressure gradient across the pulmonary vascular bed was high, while, on the other hand, the pulmonary blood flow was low.

With a few isolated exceptions, the pressures in the brachial artery were normal both at rest and during exercise. The systemic vascular resistance was also normal both at rest and during exercise.

Summary

The haemodynamic findings at rest and during exercise are reported for 51 patients catheterized approximately 18 months after surgical repair of haemodynamically uncomplicated ASD sec. The pre- and postoperative values at rest in these patients showed no deviation from the results discussed previously for the entire series.

It was of especial interest to study the circulatory efficiency, i.e. the cardiac output in relation to the oxygen uptake and heart rate. The results appeared to agree with the conditions in hypokinetic

circulation, since the majority of patients, especially the children and older adults, showed a cardiac output which, at rest, was low though within the normal range, but which increased in a normal way during exercise.

The pressures in the pulmonary circulation were normal at rest, and were, on the average, somewhat higher in children than in adults.

The pressure reaction during exercise was in agreement with previous findings (Granath et al. 1964); this reaction was more pronounced in the older than in the young patients, possibly due to age-dependent structural changes with increasing vascular rigidity and reduced elasticity in the pulmonary artery.

The mean PCV pressure was normal both at rest and during exercise; the pressure increase during exercise was somewhat more pronounced in the older than in the young patients.

The normal, or somewhat high, pressure gradient across the pulmonary capillary bed with, in many cases, a rather low pulmonary blood flow, gave rise to a somewhat high pulmonary vascular resistance both at rest and during exercise, especially in the older patients.

CHAPTER IX

Haemodynamic findings at rest and during exercise before and after operation in 18 patients

In 18 patients the pressure and flow determinations during exercise were carried out with the same work load before as after operation, and therefore in this series individual comparisons of certain haemodynamic functions could be made. These results are therefore reported separately.

In this small series no consideration has been taken of the sex differences in the young and older adults. In age group A there were 6 children (3 boys and 3 girls). In age group B, the young adults, there were 5 women and 2 men, and in age group C, the older adults, 4 women and 1 man. These patients were examined 11 months, on the average, after operation. The results from these investigations are summarized in Tables 16 and 17 and Figs. 15—23.

Circulatory function

Heart rate. The heart rate was essentially the same at the follow-up examination as before operation. In the children an average value of 87 beats per minute was noted preoperatively and 84 at the follow-up examination, and in the adults 74 and 67 beats per minute, respectively. In all patients sinus rhythm with a normal frequency was noted.

Oxygen uptake (Fig. 15). The oxygen uptake at *rest* was the same on recatheterization as preoperatively in all age groups.

During *exercise* this value rose to a normal extent with increasing work loads in the different age groups, the increase being approximately the same preoperatively as on recatheterization. The relationship between heart rate and oxygen uptake was also the same on both these occasions. The mean value for the mechanical efficiency was 18 % in the children, 22 % in the young adults and 21 % in the older adults, at a work load which increased the heart rate both pre- and postoperatively to 144 beats/min on the average in the children and 128 beats/min and 111 beats/min in the other two groups, respectively.

Arterial oxygen saturation. The arterial oxygen saturation, at *rest* and during *exercise,* lay within the normal limits both preoperatively and on recatheterization. At rest, the mean arterial oxygen saturation in the entire series was 97.9 %, and during exercise 96.5 %, with no difference between the age groups.

Oxygen saturation in superior vena cava (Fig. 16 A). At *rest,* the mean oxygen saturation of blood drawn from the superior vena cava was, on the average, 71.3 % preoperatively, and this remained unchanged (70.1 %) on recatheterization, in the children and young adults. In the older adults of age group C this value was also the same

Table 16. Observations during heart catheterization at rest and during work before and after operation in 18 cases with ASD sec.
Abbreviations as in Table 14.

Conditions and age groups		Characteristic	Heart-rate, beats/min	AVD ml/l	Oxygen uptake ml/min STPD	Cardiac output 1/min		Cardiac index 1/min per m² BSA		Stroke volume ml	
						Pulm. circ.	Systemic circ.	Pulm. circ.	Systemic circ.	RV	LV
Rest											
Preop.	A	mean	87	16.5	167	10.2	3.3	8.7	2.9	119	39
	B	»	73	20.8	234	14.0	5.2	8.4	3.0	191	68
	C	»	76	16.1	224	15.0	4.0	8.7	2.2	204	55
		min.	61	10.0	144	7.9	3.0	5.2	1.5	90	30
		max.	105	49.0	294	18.3	7.5	12.7	3.3	300	89
		SD	10.2	4.6	30.9	2.6	1.1	1.8	0.9	36.9	12.3
		SE	2.4	1.1	7.3	0.6	0.3	0.4	0.2	8.7	2.9
Postop.	A	mean	84	39.5	174		4.5		3.6		55
	B	»	63	40.4	234		5.9		3.6		94
	C	»	71	49.5	220		4.5		2.6		61
		min.	50	31.3	149		3.5		2.3		44
		max.	107	55.8	295		7.7		4.5		110
		SD	9.2	5.7	30.9		0.8		0.5		11.4
		SE	2.2	1.3	7.3		0.2		0.1		0.3
Work											
Preop.	A	mean	150	46.5	642	13.9		12.2		95	
	B	»	130	51.1	1152	23.4		14.5		181	
	C	»	112	43.0	766	19.9		11.4		177	
		min.	85	32.9	540	10.6		8.9		278	
		max.	170	67.3	1644	34.0		21.0		72	
		SD	20.4	10.2	261.3	6.9		2.9		34.1	
		SE	4.9	2.4	61.6	1.6		0.7		8.0	
Postop.	A	mean	138	83.5	644		7.7		6.0		56
	B	»	126	92.5	1280		13.4		7.8		105
	C	»	110	93.5	773		8.2		4.5		73
		min.	88	43.0	437		5.1		3.4		43
		max.	170	120.1	1644		17.0		9.8		133
		SD	20.3	17.1	234.1		2.1		1.3		12.9
		SE	4.8	4.1	55.2		0.5		0.3		3.1

$$Wi_{RV} = \frac{C_{i_P} \cdot 1.005\ (\bar{P}_{PA} - \bar{P}_{PCV}) \cdot 13.6}{1000}\ \text{kpm/min per m}^2\ \text{BSA}$$

$$Wi_{LV} = \frac{C_{i_S} \cdot 1.005\ (\bar{P}_{BA} - \bar{P}_{RA}) \cdot 13.6}{1000}\ \text{kpm/min per m}^2\ \text{BSA}$$

Stroke volume index (SV_i) ml/m² BSA		Pulm. vasc. resist. R_P	Pulm. vasc. resist. index R_{i_P}	Systemic vasc. resist. R_S	Systemic vasc. resist. index R_{i_S}	Work index (W_i)		Distensibility index (D_i)	
RV	LV					RV	LV	RV	LV
104	34	0.8	1.0	26.5	31.5	1.1	3.7	20.8	5.0
114	40	0.5	1.0	19.4	32.8	0.9	3.7	26.5	5.0
122	33	1.2	2.2	22.9	40.7	1.5	3.0	30.5	9.0
63	24	0.3	0.5	10	21	0.3	2.1	14	3
185	58	2.1	3.4	32	54	5.8	7.5	103	10
26.7	7.9	0.3	0.5	7.7	8.8	1.1	5.1	28.7	2.5
6.3	1.8	0.1	0.1	1.8	2.1	0.3	1.2	6.8	0.6
	45	1.6	1.9	18.5	23.3	0.4	4.2	14.0	5.5
	54	0.9	1.5	15.4	27.8	0.3	4.6	18.0	6.0
	37	1.8	3.2	19.5	35.0	0.2	3.7	18.5	9.0
	29	0.5	0.7	13	22	0.1	2.8	8	4
	63	3.0	4.8	24	43	0.7	6.0	51	25
	4.5	0.5	0.8	2.5	5.2	0.7	4.4	13.6	8.7
	1.1	0.1	0.2	0.6	1.2	0.2	1.1	3.2	2.1
85		0.8	1.0			2.4		28.3	
105		0.6	1.0			3.0		29.1	
102		1.4	2.3			3.5		20.4	
74		0.4	0.6			0.1		18	
143		3.1	5.1			4.5		54	
19.4		0.7	0.8			4.7		15.1	
4.6		0.2	0.2			1.1		6.2	
	46	1.6	2.2	13.3	16.9	1.0	8.5	12.8	6.0
	61	0.8	1.4	8.7	15.1	1.3	12.3	17.4	6.5
	42	1.9	3.2	15.0	25.4	0.8	7.3	15.6	4.9
	38	0.1	0.2	7	11	0.3	4.6	4	3
	85	4.1	6.7	17	32	2.7	16.3	43	10
	8.8	0.9	1.4	2.5	3.3	2.8	13.0	12.9	2.6
	2.1	0.2	0.3	0.6	0.8	0.7	3.1	3.5	0.6

$$D_{i_{RV}} = \frac{RV_{SV_i}}{RV_D}$$

$$D_{i_{LV}} = \frac{LV_{SV_i}}{LV_D}$$

on both occasions, but somewhat lower, viz. 65.4 %.

During *exercise* the values decreased in the children and young adults to averages of 63.0 % preoperatively and 55.5 % on recatheterization. In the older adults the corresponding values were 63.1 % and 64.9 %, respectively.

Oxygen saturation in pulmonary artery (Fig. 16 B). At *rest,* the mean oxygen saturation in blood drawn from the pulmonary artery was, in the whole series, 88.8 % preoperatively and 72.0 % on recatheterization, with no difference between the age groups.

During *exercise* this value decreased in the whole series to 73.3 %, on the average, preoperatively and 47.7 % on recatheterization.

Arteriovenous oxygen difference. At *rest,* the mean arteriovenous oxygen difference in the whole series was 17.8 ml/l preoperatively, with no difference between the age groups. On recatheterization this value was somewhat greater in the older adults (49.5 ml/l) than in the children and young adults (39.9 ml/l).

During *exercise* the arteriovenous oxygen difference increased preoperatively in the whole series to an average of 46.6 ml/l. On recatheterization the value was found to have increased to 83.5 ml/l in the children and to 93.0 ml/l in the adults. In relation to the oxygen uptake most of the older patients showed on recatheterization, during exercise, a rather high arteriovenous oxygen difference, but in relation to the heart rate this increase was essentially normal.

Cardiac output (Fig. 17). At *rest,* the mean cardiac output in the pulmonary circulation before the operation was 10.2 l/min in the children, 14.0 l/min in the young adults and 15.0 l/min in the older adults. The corresponding cardiac index

TABLE 17. Observations during heart catheterization. Abbreviations as in Table 14.

Conditions and age groups		Characteristic	Oxygen saturation per cent BA	PA	SVC
Rest					
Preop.	A	mean	97.9	89.0	71.2
	B	»	99.3	89.6	71.4
	C	»	96.5	87.5	65.3
		min.	90.2	85.6	59.4
		max.	100.0	94.8	85.5
		SD	1.9	2.5	5.6
		SE	0.4	0.6	1.3
Postop.	A	mean	96.8	70.8	70.8
	B	»	97.7	74.5	68.9
	C	»	98.3	70.9	65.6
		min.	95.8	69.6	59.1
		max.	99.9	81.9	75.5
		SD	1.7	3.6	3.3
		SE	0.4	0.8	0.8
Work					
Preop.	A	mean	97.1	71.7	63.9
	B	»	98.2	70.4	62.2
	C	»	94.4	79.0	63.1
		min.	84.2	60.0	53.8
		max.	100.0	81.6	70.6
		SD	2.9	4.9	2.9
		SE	0.7	1.2	1.2
Postop.	A	mean	96.6	48.9	54.3
	B	»	97.5	48.0	56.8
	C	»	95.1	46.1	64.9
		min.	93.5	33.5	39.2
		max.	100.0	55.5	75.1
		SD	1.3	6.9	7.2
		SE	0.3	1.6	2.9

tion at rest and during work before and after operation in 18 cases with ASD sec.

Pressure, mm Hg

RA	RV		PA			PCV	BA		
M	S	D	S	D	M	M	S	D	M
3.3	30	5.0	23	8	14	5.5	119	72	90
3.6	30	4.3	23	7	14	6.3	130	71	88
2.0	30	4.0	27	9	16	3.7	131	74	97
0	22	2	16	4	8	2	100	60	70
4	87	7	87	24	43	11	155	90	110
1.7	13.5	1.9	13.8	3.9	6.5	2.1	12.1	11.7	12.1
0.4	3.2	0.4	3.3	0.9	1.5	0.5	2.8	2.8	2.8
2.8	25	3.2	23	7	14	6.9	119	61	83
2.2	25	3.0	24	7	14	8.3	129	65	90
—0.4	23	2.0	19	6	10	3.8	139	68	101
—1	18	1	17	5	10	0	110	50	70
5	35	3	34	7	15	17	140	80	100
1.8	6.3	2.1	7.4	3.7	5.2	3.9	9.7	7.6	10.3
0.4	1.5	0.5	1.7	0.9	1.2	0.9	2.3	1.8	2.5
0.7	46	3.0	36	13	22	7.5	149	87	98
3.0	41	3.6	40	15	25	9.8	171	80	108
2.3	53	5.0	52	20	32	10.8	168	91	119
—1	33	4	28	10	17	4	140	70	90
9	63	6	100	25	50	15	210	115	150
2.3	5.8	0.7	7.6	4.4	5.9	3.1	18.4	13.6	20.4
0.9	2.4	0.3	1.8	1.1	1.4	0.7	4.3	3.2	4.9
1.6	36	3.7	33	15	21	8.7	145	82	101
1.6	45	3.5	38	15	23	11.4	172	81	116
0.2	47	2.7	40	17	23	9.4	171	84	115
—3	30	—5	20	5	11	2	130	85	90
10	70	15	60	30	40	20	210	100	160
2.9	9.9	4.3	10.5	6.5	8.4	3.9	16.2	11.2	14.8
0.8	2.7	1.1	2.5	1.5	2.0	0.9	3.9	2.6	3.5

values were 8.7, 8.4 and 8.7 l/min per m^2 body surface area, respectively.

The mean cardiac output in the systemic circulation was 3.3 l/min in the children, 5.2 l/min in the young adults and 4.0 l/min in the older adults, corresponding to cardiac index values of 2.9, 3.0 and 2.2 l/min per m^2 body sur-

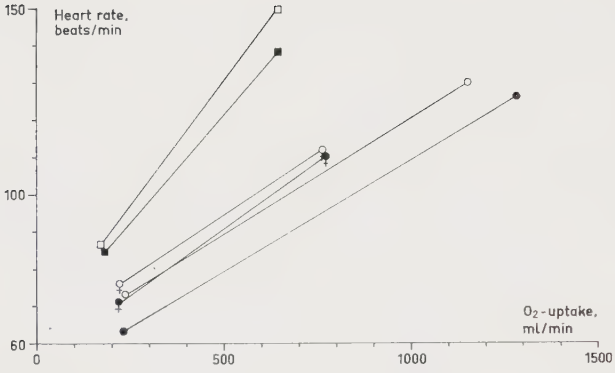


Fig. 15. Mean oxygen uptake (ml/min) in relation to mean heart rate (beats/min), at rest and during exercise on catheterization before and after operation. Squares represent children, circles young adults and circles with crosses older adults. Open symbols = preoperative values, filled symbols = postoperative values.

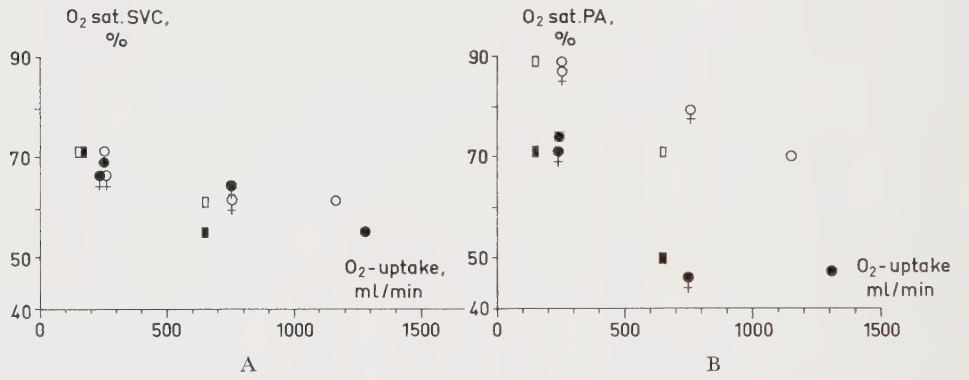


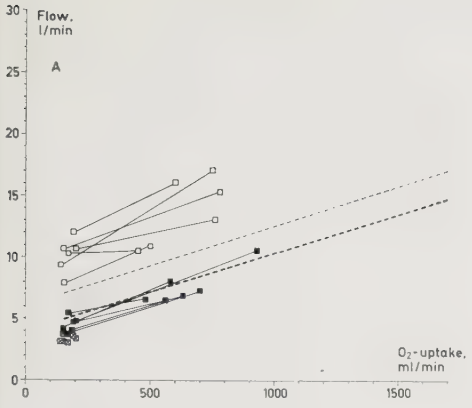
Fig. 16. Mean oxygen saturation, in per cent, in relation to mean oxygen uptake, in ml/min, in superior vena cava (SVC, Fig. 16 A) and pulmonary artery (PA, Fig. 16 B), at rest and during exercise before and after operation. Symbols as in Fig. 15.

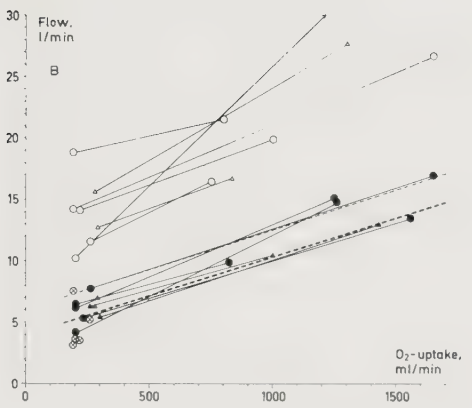
face area, respectively. On recatheterization these values were 3.6, 3.6 and 2.6, respectively.

During *exercise* the cardiac output in the pulmonary circulation increased by an average of 3.7 l/min in the children, 9.4 l/min in the young adults and 4.9 l/min in the older adults. These increases were normal and were of at least the same order of magnitude as the increases in cardiac output in the systemic circulation noted on recatheterization, except in one patient in age group C, who had pulmonary hypertension and showed a reduced cardiac output in the pulmonary circulation preoperatively.

The left-to-right shunt at rest was 6.9 l/min in the children, 8.9 l/min in the young adults and 11.0 l/min in the older adults. The corresponding values for shunt index were 5.2, 5.4 and 6.3 l/min per m^2 body surface area, respectively. When expressed as per cent of the pulmonary blood flow, the shunt was 67 % in the children, 65 % in the young adults and 73 % in the older adults.

In no case was a residual shunt noted on recatheterization.





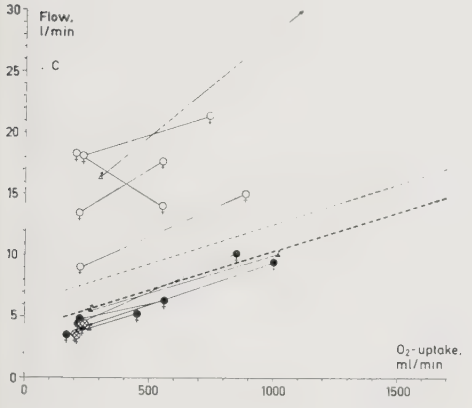


Fig. 17. Oxygen uptake (ml/min) in relation to cardiac output (l/min) in pulmonary and systemic circulation at rest and during exercise before and after operation. Regression lines between these parameters in old (heavy broken line) and young (thin broken line) normal persons according to Granath et al. (1964). Fig. 17 A shows the conditions for 6 children, Fig. 17 B for 5 women and 2 men in age group B, and Fig. 17 C for 4 women and 1 man in age group C. Squares represent children, circles women and triangles men in age group B, and circles with a cross women and triangles with an arrow men in age group C. Open symbols = cardiac output in pulmonary circulation; crossed symbols = preoperative and filled symbols postoperative cardiac output in systemic circulation. In Fig. 17 B and 17 C (see arrows in figures) there was no room for two symbols, representing values for cardiac output in pulmonary ciculation of 34 and 31.2 l/min and values for oxygen uptake of 1590 and 1120 ml/min. respectively.

Shunt group, type of defect, heart volume and systolic right ventricular pressure. 9 patients were in shunt group 2, and 9 in shunt group 3. 16 patients had a large central secundum defect, one child had a maximal large, low defect and one patient in age group C had a sinus venosus defect with anomalous right-sided venous return to the superior vena cava. 6 patients had a normal heart volume, 9 patients showed slight cardiac enlargement, and in 3 adults there was moderate or pronounced cardiac enlargement. 11 of the 18 patients showed a systolic right ventricular pressure of 30 mm Hg or more. These haemodynamic and clinical findings were in agreement with those reported for the entire series

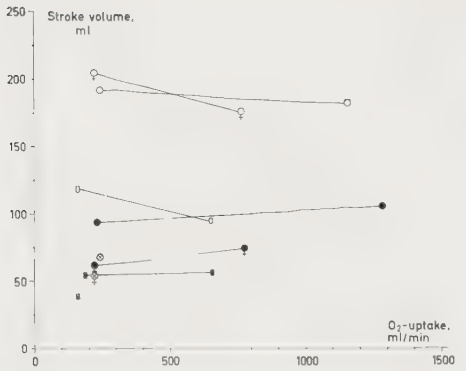


Fig. 18. Mean stroke volume (ml) in relation to mean oxygen uptake (ml/min), at rest and during exercise before and after operation. Crossed symbols = preoperative values for left ventricular stroke volume at rest. Other symbols as in Fig. 15.

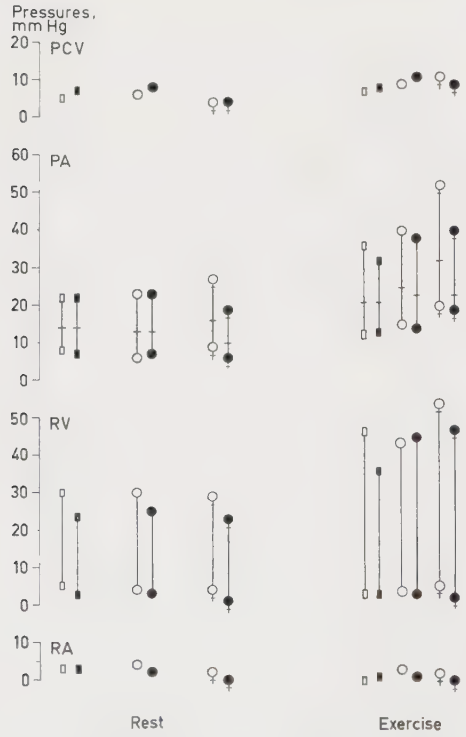


Fig. 19. Mean values for pressures at rest and during exercise before and after operation. Notation as in Table 14 and symbols as in Fig. 15.

of 107 patients. In the small series there was no significant correlation either between the preoperative values of shunt index and heart volume or between their postoperative reductions.

Stroke volume (Fig. 18). At *rest*, the mean right ventricular stroke volume before operation was 119 ml in the children, 191 in the young adults and 204 ml in the older adults. The corresponding values for the left ventricle were 39, 68 and 55 ml, respectively; on recatheterization these values at rest were found to have increased significantly (*) in the children and young adults (to 55 ml and 94 ml, respectively), but to have remained essentially unchanged (61 ml) in the older adults.

During *exercise* the right ventricular stroke volume decreased somewhat preoperatively in the children and older adults, but was essentially unchanged in the young adults. On recatheterization no change in the left ventricular stroke volume was observed in the children, compared with the resting value. In the young and older adults increases of 20 % and 10 %, respectively, of the resting values were noted.

Intracardiac and intravascular pressures

The results of the pressure measurements made preoperatively and at the follow-up examination, both at rest and during exercise, are given in Fig. 19.

Right atrium. At *rest*, preoperatively, the mean RA pressure in the whole series was 2.9 mm Hg, and on recatheterization it was significantly (*) lower, viz. 1.5 mm Hg.

During *exercise* there was a reduction

to 2.0 mm Hg preoperatively, and to 1.1 mm Hg on recatheterization.

Right ventricle. At *rest,* the systolic right ventricular pressure in the whole series was 30 mm Hg preoperatively, and 24 mm Hg, i.e. significantly lower (*) on recatheterization. The end-diastolic pressures were 4.4 mm Hg and 2.3 mm Hg, respectively.

During *exercise* the systolic pressure increased both preoperatively and on recatheterization, to averages of 46 mm Hg and 36 mm Hg, respectively, in the children, and to 47 mm Hg and 46 mm Hg in the adults. The end-diastolic pressures were 3.7 mm Hg and 3.2 mm Hg, respectively.

Pulmonary artery. At *rest,* the systolic pressure in the whole series was, on the average, 24 mm Hg preoperatively and 22 mm Hg on recatheterization. The diastolic and mean pressures were also normal, the mean pressures being 15 mm Hg and 13 mm Hg, respectively. The systolic pressure gradient between the right ventricle and pulmonary artery was, at rest 5 mm Hg preoperatively and 2 mm Hg on recatheterization. One patient had pulmonary hypertension with a systolic PA pressure of 87 mm Hg.

During *exercise* the systolic pressure in the pulmonary artery increased preoperatively to an average of 38 mm Hg in children and young adults and to 52 mm Hg in older adults. The corresponding mean pressure values were now 23 mm Hg and 32 mm Hg, respectively. On recatheterization the systolic pressures were found to have increased to 37 mm Hg and the mean pressure to 23 mm Hg, in the whole series, with essentially no difference between the age groups.

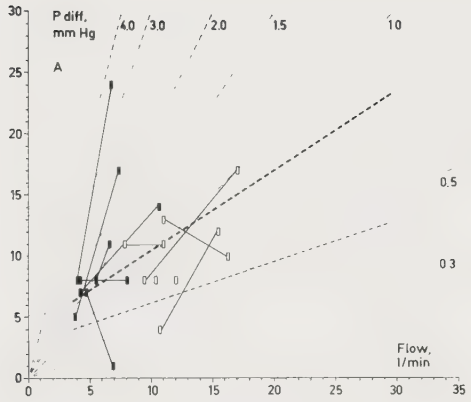
Pulmonary capillary venous pressure. At *rest,* the mean PCV pressure preoperatively was 5.9 mm Hg in the children and young adults and 3.7 mm Hg in the older adults. The corresponding values noted on recatheterization were 7.6 and 3.8 mm Hg, respectively.

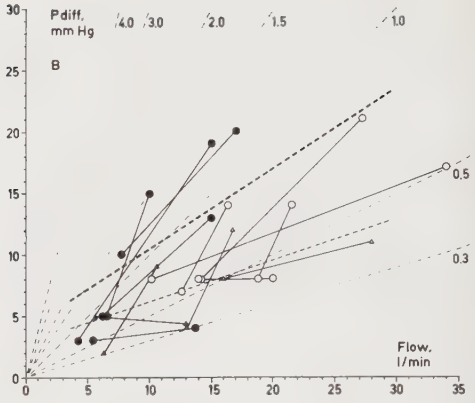
During *exercise* the mean PCV pressure increased preoperatively to 7.5 mm Hg in the children and to 10.3 mm Hg in the adults, while the corresponding values obtained on recatheterization were 8.7 and 10.4 mm Hg, respectively.

Brachial artery. At *rest,* the systolic pressure in the brachial artery preoperatively was, on the average, 119 mm Hg in the children and 130 mm Hg in the adults, while the mean pressures were 90 mm Hg and 92 mm Hg, respectively. On recatheterization no change was noted at rest in these pressures.

During *exercise* the systolic pressures increased to similar extents preoperatively and at recatheterization, i.e. to 147 mm Hg in the children and to 170 mm Hg in the adults; the corresponding values for the mean pressures being 99 mm Hg and 114 mm Hg, respectively.

Left atrium. The mean pressure in the left atrium was recorded in 14 cases, and was found to be 5.2 mm Hg in the children and young adults, and 2.7 mm Hg in the older adults. The difference in mean pressure between right and left atrium was 1.8 mm Hg in the children and young adults and 0.7 mm Hg in the older adults. The difference between mean PCV pressure and mean pressure in the left atrium was, on the average, 0.8 mm Hg. The preoperative difference





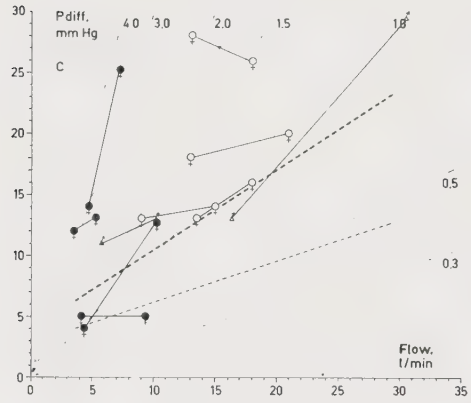


Fig. 20. Relationship between pressure gradient (Pdiff) across the pulmonary vascular bed, in mm Hg, and cardiac output (CO), l/min, at rest and during exercise before and after operation. Pdiff expressed as the difference in mean pressure between PA and PCV in mm Hg. Very thin broken lines represent different isoresistance lines (R). The other broken lines are regression lines for these parameters for old (heavy lines) and young (thin lines) normal persons according to Granath et al. (1964). Symbols as in Fig. 17.

Fig. 20 A shows the conditions in age group A; for 2 children there was no resistance determination during exercise preoperatively. Fig. 20 B shows the conditions in age group B, and Fig. 20 C in age group C.

in mean pressure between PCV and right atrium was 2.5 mm Hg for the children and young adults and 1.7 mm Hg for the older adults. On recatheterization these values were found to be 5.1 mm Hg and 4.2 mm Hg.

Left ventricle. The systolic pressure in the left ventricle was 104 mm Hg in the children and young adults and 127 mm Hg in the older adults. The end-diastolic pressures were 7.4 mm Hg and 3.7 mm Hg, respectively.

Pulmonary vascular resistance (Fig. 20). At *rest*, the pulmonary vascular resistance was 0.8 in the children, 0.5 in the young adults and 1.2 in the older adults, preoperatively, and 1.6, 0.9 and 1.8, respectively, on recatheterization. There was thus an average increase in all three groups: in the children (**) and young adults (*) this was statistically significant but not in the older adults.

During *exercise* no statistically certain change in the pulmonary resistance was noted either preoperatively or at recatheterization, compared with the respective resting values. In one half of the patients a decrease in pulmonary vascular resist-

ance was seen, but there were large individual variations.

Systemic vascular resistance. At rest, preoperatively the systemic vascular resistance was 26.5 in the children, 19.4 in the young adults and 22.9 in the older adults, and on recatheterization 18.5, 15.4 and 19.5, respectively. This meant a significantly reduced value in the children (**) but no significant change in the adults.

Ventricular work index (Fig. 21). The ventricular work index (see equation in Table 16) was calculated according to Dexter (1951). For the right ventricular work index a significant (***) reduction was noted on recatheterization, both at rest and during exercise, compared with the preoperative values. The left ventricular work index was significantly (*) higher postoperatively, at rest. Preoperatively, the right ventricular work index was somewhat higher in the older than in the young patients, both at rest and during exercise.

Ventricular distensibility index (Fig. 22). The ventricular distensibility index (see equation in Table 16) was calculated according to Rowe et al. (1961), and for the right ventricle this was significantly (**) lower postoperatively than preoperatively, both at rest and during exercise.

The distensibility index for the left ventricle was assessed with the reservation that for the postoperative value an approximate value for the left ventricular end-diastolic pressure, calculated from PCV, had to be used. The left ventricular distensibility index, at rest, was the same postoperatively as preoperatively, and was significantly (***) lower than the right ventricular distensibility index.

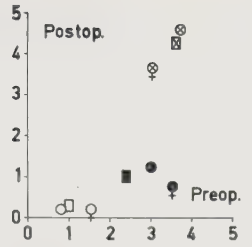


Fig. 21. Ventricular work index at rest and during exercise before and after operation.

Symbols: Squares = children, circles = young adults and circles with a cross = older adults. Open symbols = right ventricular work index at rest. Filled symbols = right ventricular work index during exercise. Crossed symbols = left ventricular work index at rest.

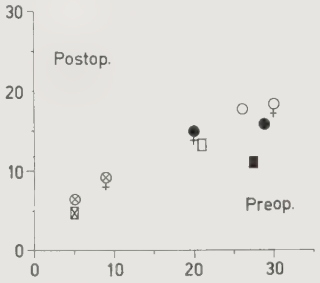


Fig. 22. Ventricular distensibility index at rest and during exercise, before and after operation.

Symbols: Squares = children, circles = young adults and circles with a cross = older adults. Open symbols = right ventricular distensibility index at rest. Filled symbols = right ventricular distensibility index during exercise. Crossed symbols = left ventricular distensibility index at rest.

Discussion

The predominant haemodynamic finding in uncomplicated atrial septal defect of the secundum type is the left-to-right shunt, where a volume corresponding to the size of the shunt is ineffective both

as regards oxygen transport and muscular work capacity. The left-to-right shunt involves, in particular, increased work for the right ventricle, while, on the other hand, the work of the left ventricle is unchanged or possibly somewhat reduced with a decrease in the systemic flow.

During exercise the size of the left-to-right shunt in atrial septal defect cannot be determined with the current methods of blood-gas analysis. An approximate estimate can be made during exercise, however. At rest the output of the left ventricle is normal or somewhat low, while that of the right ventricle is greatly increased. During exercise the output of the right ventricle may increase to a smaller extent than normally, and the stroke volume of the right ventricle decreases considerably, with the result that the left-to-right shunt decreases to the advantage of the left ventricular output, which is augmented. If the output of the right ventricle increases to a normal extent, it may be expected that the shunt will remain unchanged. If, on the other hand, the shunt were to increase during exercise, this would result in a pronounced increase of the output of the right ventricle. If the left-to-right shunt were to decrease greatly, or entirely, this would result in a reduction of the saturation value in the pulmonary artery to a level which, with respect to work, was normal, i.e. 40—50 %.

In all but two patients the flow in the pulmonary circulation increased preoperatively during exercise, the exceptions being the patient with pulmonary hypertension and a girl in age group A. Fig. 17 shows that in the three age groups this increase was approximately of the same order of size as that noted on recatheterization. This indicates that during exercise the left-to-right shunt in l/min in these patients was essentially unchanged, with a probably normal increase in the output of both the right and left ventricles. This is supported by the fact that the preoperative reduction of the saturation values in the pulmonary artery during exercise was very moderate compared with the result obtained on recatheterization, and also by the fact that preoperatively the right ventricular stroke volume decreased only negligibly during exercise.

Jonsson et al. (1957) found that the left-to-right shunt in atrial septal defect decreased during exercise in 5 of 10 patients, but recently, Davies and Gazetopoulos (1966) observed that in atrial septal defect with low pulmonary vascular resistance there were parallel increases in the systemic and pulmonary flow during exercise with little change in the magnitude of the left-to-right shunt. This is in closer agreement to the present results, which also show this tendency on more strenuous exercise. In their series of 5 patients, Davies and Gazetopoulos had lower work loads throughout in their exercise tests, corresponding to an average oxygen consumption of 460 ml/min.

As in the larger present series of patients who underwent follow-up examination, a low cardiac output at rest, with a tendency to a hypokinetic circulation during exercise, was noted in this smaller group also. In addition, the cardiac index in the systemic circulation

at rest was significantly lower preoperatively in the children (**) than at recatheterization, but in the adults it was only slightly lower. Preoperatively, however, in consideration of the cardiac output in the pulmonary circulation the cardiac output in the systemic circulation increased to a probably normal extent during exercise. It may thus be assumed that, in these patients, even before the operation there was a tendency to hypokinetic systemic circulation with a low left ventricular output during exercise.

In order to compare the mechanical efficiency of the ventricles before and after the operation the ventricular work index and distensibility index were calculated. At rest, both these indices showed a significant reduction for the right ventricle on recatheterization. The different haemodynamic parameters which may be related to the left-to-right shunt in atrial septal defect have long been subjected to investigation; Rowe et al. (1961), who studied such parameters at rest, found that the only significant correlation was that between the size of the left-to-right shunt and the difference in distensibility index between the right and left ventricle. In Rowe's study, however, 4 out of 24 patients had pronounced pulmonary hypertension of the obstructive type, in three cases combined with a right-to-left shunt. In the present series there was no correlation between distensibility index and left-to-right shunt.

The shunt volume in atrial septal defect is governed predominantly by the diastolic distensibility of the right ventricle. Dexter (1956) found that the

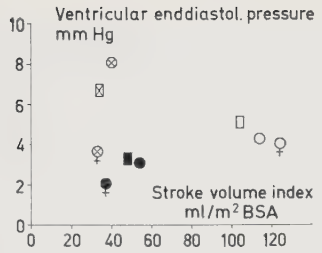


Fig. 23. Ventricular end-diastolic pressure (mm Hg) in relation to ventricular stroke volume index (ml/m² body surface area). Squares = children, circles = young adults and circles with cross = older adults. Open symbols = preoperative, and filled symbols = postoperative right ventricular stroke volume index. Crossed symbols = preoperative left ventricular stroke volume index.

capacity of the right ventricle to pump large volumes with a low filling pressure differs somewhat from the conditions in the left ventricle which (according to Starling's law) requires increasing filling pressures for increasing stroke volumes. When, in the present series, the end-diastolic pressure of the right ventricle is plotted against the stroke volume index of the right ventricle, the output of the right ventricle preoperatively is found to be large in relation to the end-diastolic pressure of the right ventricle, which lies at a normal level (Fig. 23). The preoperative end-diastolic pressure in the right ventricle was significantly higher (*) than at the follow-up examination, as also was the mean pressure in the right atrium. These pressures were probably sufficiently high to permit, in view of the distensibility and function curves of the ventricles, a large increase in filling of the right ventricle. The distensibility is determined mainly by the ventricular

wall thickness, which in turn is influenced by the systolic ventricular pressure and stroke volume. But, like the mean pressure in the atrium, for technical reasons the end-diastolic ventricular pressure is also often difficult to determine and compare. Obviously this limits the value of the distensibility index in the present calculations. With this reservation the distensibility index for the right ventricle was determined in the present series, however, and was found to be 25, on the average, preoperatively, and 17, i.e. significantly lower (**) at the follow-up examination.

Depending on the degree and type of outflow obstruction in the right ventricle, the end-diastolic right ventricular pressure varies more than the pressure difference across the pulmonary vascular bed. Relatively accurate values can be obtained for the distensibility index for the left ventricle preoperatively, whereas postoperatively the estimated values are only very approximate.

It seemed therefore more adequate to calculate the mechanical efficiency on the basis of the ventricular work index, which also can be determined more accurately during exercise. Postoperatively the right ventricular work index was significantly (***) lower, and the left significantly (*) higher than preoperatively. This may be an indication of satisfactory restitution of the ventricular function postoperatively, despite the greatly increased load on the right ventricle before the operation.

In this series the pressures have also been reported with a view to comparing the pressure reaction during exercise before and after the operation. Preoperatively these pressures, with the exception of the PCV pressure, lay at the upper normal limit, and on recatheterization those in the right atrium and ventricle were significantly reduced (*), while the pulmonary arterial pressure was somewhat lower. The PCV pressure remained essentially normal.

During exercise there was no significant difference between the preoperative values and those obtained on recatheterization for the pressures in the pulmonary artery. The pressure reaction during exercise was normal in these patients on recatheterization and therefore the preoperative pressure reaction can also be regarded as normal in spite of the greatly augmented pulmonary blood flow at that time. A largely increased cardiac output in the pulmonary circulation at rest, with high normal pressures in the pulmonary artery and a low flow resistance across the pulmonary vascular bed thus allowed normal circulatory adaptation during exercise.

The pulmonary vascular resistance was somewhat higher throughout in the older than in the young patients both preoperatively and at the follow-up examination, at rest and during exercise.

At recatheterization the pulmonary vascular resistance at rest was significantly higher in the children (**) and young adults (*) than preoperatively, which is explained by the fact that after the operation the pressure reduction over the pulmonary vascular bed was usually considerably less pronounced than the decrease in the pulmonary blood flow. In the older adults the pulmonary vascular resistance was found on recatheterization to be slightly higher, but still at the

upper normal level, and in these patients the postoperative pressure reduction in the pulmonary artery was, on the average, somewhat more pronounced than in the children and young adults.

During exercise, however, an abnormal reaction was noted in half of the patients, with increased pulmonary vascular resistance, but no relationship was found between this reaction and either the physical work capacity, preoperative shunt or heart size.

The pressures in the brachial artery were normal both at rest and during exercise, with no difference between the preoperative values and those obtained on recatheterization. The systemic vascular resistance showed some reduction on recatheterization, but the values remained within the normal limits.

Summary

The results from haemodynamic investigations at rest and during exercise in 18 patients before and 11 months, on the average, after surgical repair of ASD sec are reported. One patient had pulmonary hypertension before the operation, but the values for the remaining patients did not deviate essentially from those reported for the whole series. Since the exercise tests were performed with the same work loads before as after operation, individual comparisons of the haemodynamic results could be made.

The heart rate and oxygen uptake were the same postoperatively as preoperatively, both at rest and during exercise. An approximate evaluation of the magnitude of the left-to-right shunt during exercise was made by comparison between the pre- and postoperative flow conditions in the systemic and pulmonary circulations; the shunt appeared to remain unchanged by exercise. A tendency to hypokinetic circulation was observed postoperatively, and this was probably more pronounced before the operation.

The distensibility index for the right ventricle was significantly higher (**) preoperatively than postoperatively, both at rest and during exercise; at rest, this index was significantly higher (***) for the right than for the left ventricle, both pre- and postoperatively.

A more accurate indication of the mechanical efficiency of the ventricles was the work index. This was significantly lower (***) postoperatively for the right ventricle, and this indicated satisfactory restitution of the ventricular function despite the preoperatively greatly increased work load for the ventricle.

The pressures at rest, pre- and postoperatively, agreed with previously reported values for normal persons. The pulmonary vascular resistance values lay, on the average, within the normal limits both at rest and during exercise, but preoperatively they were usually low and postoperatively somewhat higher. During exercise, however, an abnormal increase of the pulmonary vascular resistance was noted in half of the patients. There was no relationship, however, between this reaction and either physical work capacity, preoperative shunt or heart size.

There was no statistically significant correlation either between the preoperative values of shunt index and heart volume or between their postoperative reductions.

General discussion and conclusions

The evaluation of the operation results in this series is based both on comparisons between preoperative and postoperative findings, where the patient serves as his own control, and on comparisons of these values with known values from healthy normal subjects. In this way an idea is obtained of the *effect of the operation*. The absence of a control series means, however, that no opinion can be expressed with certainty as to the *prognosis without operation* since, as discussed in the introduction, the variations in the natural history of the disease are wide.

In this series the indication for operation was a left-to-right shunt of at least 30 % of the pulmonary blood flow. With the low mortality figure and the low frequency of severe complications with the operation methods used here, it was justifiable to accept patients with small shunts also for operation.

The impression is obtained that the most suitable time for operation is at pre-school or school age. In this age group (age group A), both the duration of hospitalization and the convalescence period were considerably shorter than in adults. From social and psychological aspects, also, an operation is probably more easily acceptable in children, where the operation often is of a preventive nature. The indication for operation in adults may, on the other hand, be somewhat narrower, but surgery should be advised with shunts of 50 % or more of the pulmonary blood flow.

The physical cardiac findings both before and after operation were in agreement with those usually found in cases with ASD sec. In this series no relationship was found between the duration of the QRS complex and the degree of splitting of the second heart sound, either before or after operation, and therefore the residual pathologically split second sound, which was the most characteristic postoperative physical cardiac finding, can probably be explained by reduced elasticity in the pulmonary artery. Preoperatively, from the diagnostic point of view, the splitting of the second heart sound and the diastolic filling murmur are the most important physical findings. Together with the typical ECG pattern and chest roentgenogram these findings, in most cases, form the basis for the final diagnosis in ASD sec. But the cardiological findings are not always typical and, furthermore, cannot usually provide any information about the presence or absence of anomalous venous return, so that up to now heart catheterization has been included in the clinical routine examination. In the present series the fact that the ASD sec was combined with partial anomalous pulmonary venous return in 19 per cent did not influence the choice of operation method, but this is conceivable in isolated cases. In cases with partial anomalous pulmonary venous return an angiocardiography can give valuable information, while on the other hand in uncomplicated ASD sec

this investigation is hardly considered justifiable nowadays, since it has been found difficult to assess the position and size of the defect with certainty.

In the differential diagnosis between atrial septal defect of the secundum type (dorsal defect) and atrial septal defect of the primum type (ventral defect), the value of an angiocardiography is very limited owing, in particular, to the difficulty in determining with certainty the lower margin of the defect. Correct differentiation between these two types of defect is the deciding factor for the choice of operation method, since patients with a primum defect can only be operated on with the aid of extracorporeal circulation. The ECG pattern is the main guiding factor for this differential diagnosis (Toscano Barboza et al. 1958, Arntzenius et al. 1963). In the present series extracorporeal circulation was used in four cases, where a primum defect could not be excluded. These patients showed the ECG pattern of the transitional, non-classic ASD sec type which can occur with a primum defect.

In spite of the perimyocardial disturbance in the postoperative stage, no signs of constrictive reaction were seen in this series at the follow-up examination, which may have been due to the fact that the pericardium was left open at the operation. The residual pathological T wave which became "normal" only during the exercise test, and was observed in 37 per cent of the cases, is difficult to assess from a prognostic aspect. In these patients, however, the myocardial metabolism during hypothermia and coronary perfusion is unknown. Up to the present, however, these T wave changes have not been found to be prognostically unfavourable, and should not give reason for an especially prolonged convalescence period for the patient in question.

The preoperatively low filling pressure in the left ventricle may explain the fact that a number of cases showed a low normal or reduced left ventricular output. These changes in the central circulation also resulted in a tendency to hypokinetic systemic circulation with reduced cardiac output in relation to oxygen uptake. Preoperatively the oxygen saturation in the superior vena cava was at a low normal level, but increased significantly (***) after the operation to a normal value. This may be an expression of a regulative mechanism with preoperatively increased peripheral utilization of the oxygen content.

In uncomplicated cases of ASD sec, closure of the defect restores the normal pressure conditions and creates the prerequisites for a normal central circulation. In spite of this, however, in a number of cases, especially children and older adults, a tendency to hypokinetic circulation was observed at the follow-up examination. In such cases controlled physical training, introduced gradually, should be appropriate, and should improve the systemic circulation, and also, the psychological condition. This applies particularly to older patients, in whom a tendency to a long convalescence period probably has the directly opposite effect.

In uncomplicated cases of ASD sec the period of convalescence in adult patients should not necessarily be much longer than in children, and 6—8 weeks would seem sufficient.

General summary

The main purpose of this investigation was to study the results of open heart surgery in atrial septal defects of the secundum type (ASD sec). The study was made on 107 patients, comprising a haemodynamically uncomplicated, uniform series of atrial septal defects of the secundum type, examined before and, on the average, 17 months after the operation.

Open repair was performed under hypothermia in 94 patients and with the aid of extracorporeal circulation in 13 patients. All patients were operated on by the same surgeon (V. O. Björk). The postoperative mortality was as low as 0.9 % and the total mortality 2.6 %.

The clinical features and cardiological findings before and after operation were studied.

The ECG pattern before and after operation, the development of the ECG changes immediately after the operation and the ECG reaction during exercise tests at the follow-up examination were analysed.

Haemodynamic studies were made by means of heart catheterization before the operation to estimate the significance and size of the left-to-right shunt and at the follow-up examination to prove that the defect was closed, but also for determination of circulatory dimensions at rest and during exercise for comparison with normal persons.

From a clinical aspect it was important to know not only that the defect was completely closed but, above all, the general cardiac condition of the patient after the operation.

The patients were divided into three age groups according to age at the time of operation, as follows: A paediatric group of 50 patients below the age of 15 years, a group of 29 young adults of ages 15—29 years, and a group of 28 older adults of 30 years of age or older.

The patients were also classified into function classes, and shunt and X-ray groups.

The murmur was usually discovered at a routine examination during the preschool or school period, but was often rediscovered at a later examination. Only 5 out of 107 patients had sought medical advice for symptoms which could be related to cardiac disorder. Preoperatively, 44 patients had symptoms. The functional deterioration began after the age of 20 years.

After the operation almost all patients were symptom-free, but no significant change in the physical work capacity was found.

The physical findings before and after operation in this series were in agreement with previous findings in uncomplicated ASD sec. The excess volume load on the right heart and pulmonary

circulation disappears instantly after repair of an atrial septal defect. Normalization of heart sounds and murmurs, and also of the roentgenological heart volume takes place gradually. A faint systolic murmur was heard, however, after the operation, probably caused by turbulent flow through the still dilated pulmonary artery. Reduced elasticity in the wall of the pulmonary artery may also explain the extensive splitting of the second heart sound after the operation while, compared with the preoperative conditions, the reduced flow volume may allow some physiological variation of the sound components.

In many cases of the present series there was some relationship beween the size of the left-to-right shunt and the heart volume, but no significant correlation was found. A significant reduction was found in the roentgenological heart volume after the operation, however. On the other hand there was no statistically certain correlation between shunt reduction and reduction of heart volume.

On comparing the QRS pattern before and after operation it was found that this pattern in lead V_1 remained unchanged, i.e. pathological, in about 50 % of the cases. Even though the *type* of QRS complex remained unchanged, however, the *degree* of abnormality decreased. The amplitude reduction may correspond to regression of hypertrophy and/or dilatation in the right ventricular outflow tract. A residual pathological QRS pattern may point to a congenital abnormality in the right bundle branch, which will persist after surgery.

A pathological QRS complex in lead V_1 was not an expression of residual shunt.

At the follow-up examination a residual pathological T wave was found, and a normalization of this T wave during exercise was observed. The reason for this "status post myocardial lesion" reaction is discussed and is considered to be of no functional importance. This pathological T wave in the precordial leads at rest, though observed for a long period after the operation, should not be regarded as unfavourable.

Before the operation the left-to-right shunt in the entire series was, on the average, 61 % of the pulmonary blood flow.

At the follow-up examination no residual shunts were found. The oxygen saturation in the superior vena cava lay at a normal level at the follow-up examination but was significantly higher than before the operation.

The postoperative pressure reaction in the pulmonary circulation, with reduction from preoperatively slightly raised or high normal pressure levels to normal values, was explained by the hyperkinetic effect of the left-to-right shunt. Only in older adults was there a significant correlation between shunt size and systolic right ventricular pressure, but at the follow-up examination no correlation was found between pressure reduction and shunt.

On comparing the filling pressure of the ventricles before and after the operation it was found that, preoperatively, this pressure was raised for the right ventricle and, in many cases, was lowered for the left. This change in the central circulation resulted in many cases in a low normal or reduced left ventricular

output with a tendency to hypokinetic circulation. Preporeratively the oxygen saturation in the superior vena cava was at a low normal level, and this may be an expression of a regulative mechanism with increased peripheral utilization of the oxygen content.

The circulatory efficiency, i.e. the cardiac output in relation to oxygen uptake was analysed in a series of patients at the follow-up examination. The results appeared to agree with the conditions in hypokinetic circulation. Children and older adults, especially, showed low values for cardiac output both at rest and during exercise. This, in combination with a "high normal" pressure gradient across the pulmonary capillary bed gave rise to a somewhat high pulmonary vascular resistance.

In 18 patients individual comparisons of haemodynamic conditions before and after operation were made, both at rest and during exercise. An approximate evaluation of the magnitude of the left-to-right shunt during exercise was made by comparison between the pre- and postoperative flow conditions in the systemic and pulmonary circulation, and this showed that the shunt appeared to remain unchanged by exercise. A tendency to hypokinetic systemic circulation was observed postoperatively and may have been more pronounced before the operation.

In uncomplicated cases of ASD sec, closure of the defect creates the prerequisites for a normal circulation. In patients with a tendency to hypokinetic circulation after the operation controlled physical training should improve the systemic circulation.

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